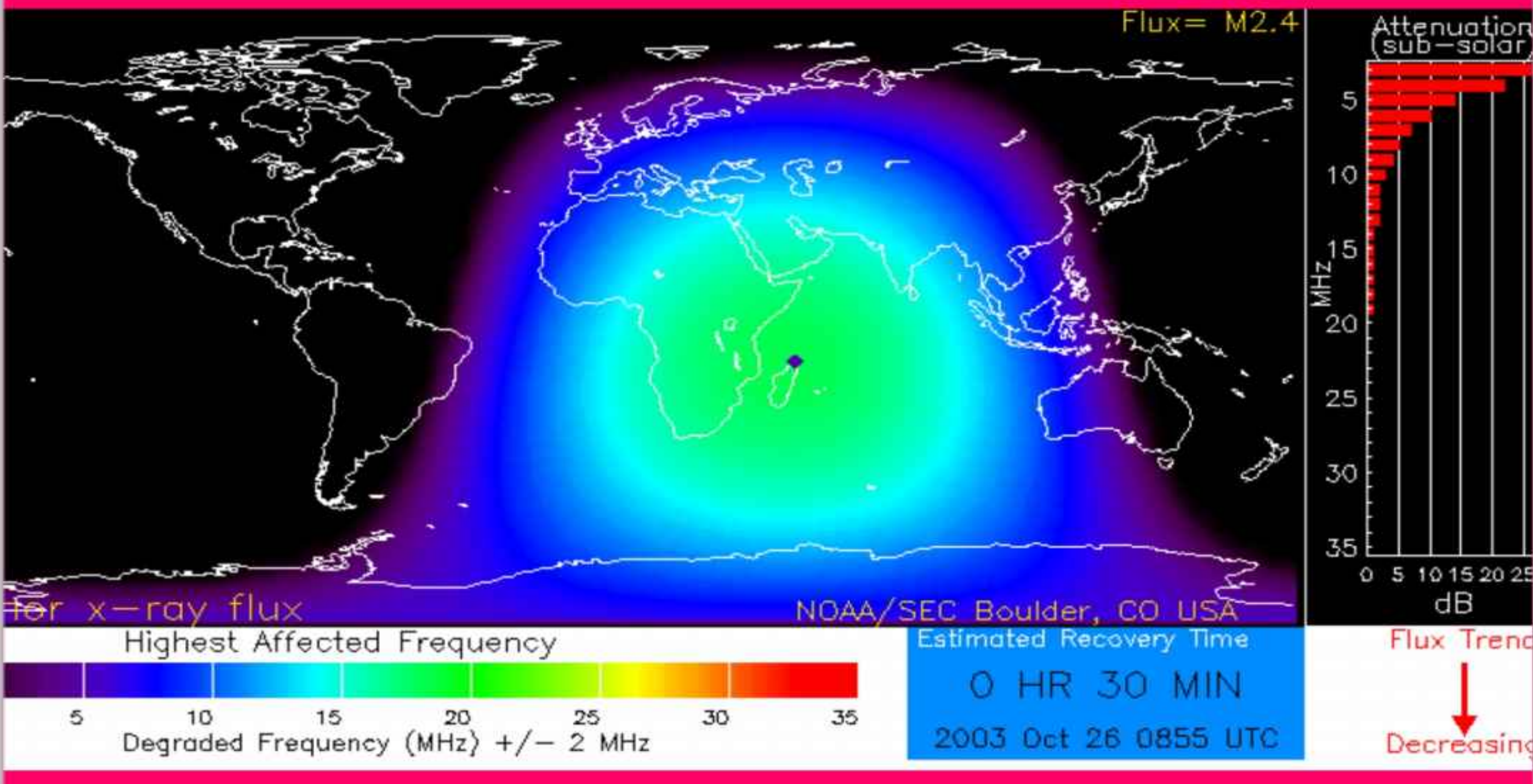
AMATEUR RADIO PROPAGATION STUDIES

FLAVIO EGANO, IK3XTV



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"At any given moment, every day of the year, there are radio amateurs scattered across the world who are continuously listening and transmitting on our frequencies. When you switch on your radio, you will never be alone."

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Credits

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The Ham radio maps, were created by the author with DX ATLAS Software created by Alex Shovkoplyas, VE3NEA. www.dxatlas.com.

Maps of MUF Analysis were made with “VOACAP Online (www.voacap.com), Jari Perkiömäki OH6BG".

Some images were taken from screen shots of the WSJT program, by J. Taylor, K1JT.

All the sources have been reported directly in the contextual pages of the book, or in the final pages under the heading References, Bibliography and Acknowledgments.

Cover image: D region absorption by Space Weather Prediction Center-NOAA (Image public domain).

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Preface

This book is a collection of studies and firsthand experiences gathered over many years of engagement in amateur radio activities. It does not aim to be a radio propagation manual or a text on ionosphere physics. Instead, it should be understood as a personal diary of the author, akin to a "ship's log." While parts of the book may take the form of a manual, others resemble a diary.

Please pardon any repetition or overlapping topics, as the intention was always to contribute something unique to the narrative. I have endeavored to consolidate years of research and experiments conducted with fellow amateur radio enthusiasts from around the world. My aim was to

shed light on various propagation phenomena and anomalies, seeking plausible explanations without claiming to present an absolute truth, but offering hypotheses from the perspective of an amateur radio enthusiast. I extend my heartfelt gratitude to Giorgio Marchi, IKUWL, for his collaboration in all the studies on EME propagation that we undertook together. His knowledge and experience have been invaluable in my learning process.

In an era where everything and everyone is interconnected globally through devices that can accomplish anything, radio may seem outdated, ancient, and even prehistoric. However, these devices are mere conduits of cold, digital signals, restricted within a network. Radio, on the other hand, retains the timeless allure of a message traversing the vast expanse of space and sky, reaching every corner of the world. It can even reach the moon, as demonstrated by EME propagation. Does this seem antiquated to you? Does the sky appear limited?

I express my gratitude to the radio amateurs I have connected with and who have assisted me throughout these years. I would like to mention two individuals, both of whom are now "Silent Keys" as they passed away a few years ago. The first is Marino Miceli, I4SN. Much of what is contained in this book stems from my studies of his publications and the numerous articles he wrote for "Radio Rivista," the official magazine of ARI, the Italian Amateur Radio Association. His writings ignited my passion for propagation studies. The other

individual is Adolfo Brochetelli, IK1DQW, with whom I exchanged many emails, engaging in discussions and comparisons regarding propagation. Adolfo, a retired radiotelegraph officer of the Italian navy, offered me invaluable insights based on his experience, enhancing my understanding of HF propagation. I am indebted to ham radio, as it has made the world smaller for me and taught me to think on a larger scale. Please forgive my poor English, as well as any grammatical or syntax errors. You will not find perfection in these pages, but I am still pleased to have translated my book to make it accessible to all interested individuals.

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Introduction

In this book I would like to tell the story of my research and my experiences on the propagation of radio waves. I apologize if the book contains any errors or misinterpretations of radio phenomenon.

The first part of this book is like a manual (up to page 20), but I tried to minimize it. I thought it was a good idea to provide general information on the ionosphere and propagation. I am aware that this will be boring to the reader. To make a cycling comparison, it is a bit like the climb you must face to get to the top, then when you get to the top, you take a breath and then, you savor the taste of the descent.

My hope is this. After this first part, I continue with my role as observer, where I have made experiments to verify the theory. The goal was to mix theory and practice with the right doses, but I am a bad cook and therefore I do not guarantee good results. I do not have the explanation for everything, but I have tried to find it and since I am curious by nature, I have tried to describe the behavior of the propagation in each single band (here again, I was forced to write some theory), aware of how elusive the propagation is. Sometimes it is not measured in minutes, but in moments. Many times, I missed a DX for a moment and many others I managed to do a Dx for another moment. But in this, there is all the charm of our activity. If there were not this uncertainty, a mobile phone would be enough.

That is the reason, because I have devoted a lot of time and several pages to one of the most elusive phenomena, which every radio amateur knows, because anyone has come across it at least once. This is the sporadic E. In a single moment, what was not you hoped to happen even in a year, can happen in that moment. More you study it, more it escapes from you, but I think, I understand something more, but I understand that a prediction of the

event is impossible. It is like predicting lottery numbers. But it is a fun lottery.

Then there is the whole part dedicated to my EME activity. The fascination of the Moon and of a signal that travels for hundreds of thousands of kilometers, beyond the earth's ionosphere, in the outer space, arrives on the Moon, bumps into it and then comes back. And the time it takes to go all this way can be seen on your computer screen. It is magic when you can visualize those two and a half seconds of delay, the time it takes for the radio wave to go to and from the Moon. You can "see" the speed of light. All this was made possible by digital technology and a genius like Joe Taylor, K1JT. I still remember my first contact via the Moon. I almost did not believe it. I felt like I was one of the heroes of the Apollo mission. I too had conquered the moon.

Then I tried to study that kind of propagation. I realized how the ionosphere interacted in a decisive way on the radio waves that cross it. You will also find this, inside the book. And finally, the Meteor scatter. A technique that has something of alien. But do not get me wrong. In this case the aliens are metal "stones" that come from who know where, but surely from outer space and therefore they are alien to our dear and old earth. Our waves hit those wandering stones and thanks to those "aliens" they are reflected on the earth. The new digital technologies help a lot here too, but they must always remain a means, not an end. This book has not to read as a novel or short story. It should be read one piece at a time, jumping from one topic to another. Almost like a sports newspaper. I tried everything not to bore the reader, I hope I succeeded.

An Indian saying goes: If you cannot have a horse, get a donkey You do not need big means. You have no idea what you can do with a piece of wire and 100 watts. My philosophy is that simplicity is everything: "Less is more". The lighter you are, the better you can move and keep

going. Turn on your radio, listen and follow the propagation, which is governed by the sun ... as Dante Alighieri wrote: “*The love that moves the sun and the other stars.*”

Image: Artist's conception of the Milky Way galaxy. (Wikipedia – Public domain).

Elements of radio Propagation

HF propagation - General considerations

High-frequency (HF) waves, commonly abbreviated as HF, cover the frequency spectrum ranging from 3 MHz to 30 MHz, corresponding to wavelengths between 100 and 10 meters. Unlike other frequency ranges in the radio field, HF waves enable long-distance connections with minimal power, defying the curvature of the Earth. Additionally, this range of frequencies is reflected towards the Earth's surface by ionized layers present at various heights in the atmosphere, a discovery credited to Edward Victor Appleton. The ionization of atmospheric gases is caused by the solar wind, which exhibits periodic fluctuations with significant peaks and troughs occurring approximately every 11 years. During the peak phase of each cycle, the ionospheric reflective layers remain active even at night, facilitating very long-distance communication with low power requirements.

The ionosphere, in its lower part spanning from 40 to 300 km, can be divided into three reflective layers:

- **Layer D, up to 90 km high, active around the central hours of the day**
- **Layer E, between 90 and 120 km high, has a maximum activity during the summer months**
- **Layer F, over 130 km high, during the day this layer is divided into substrates (F1 andF2).**

These are the typical characteristics. But like all things, they have various nuances and anomalies. Since the devil is hiding in the details, I tried to reveal these.

Grey line propagation

When the entire communication route is in darkness, minimal absorption occurs, creating optimal conditions for long-distance transmissions. The pinnacle of effective communication potential is reached around sunset, precisely when the correspondent experiences the reverse situation. During sunrise and the subsequent few hours, the F region of the ionosphere becomes particularly dynamic, and its refractivity exhibits an ascending gradient due to the rising sun. Along the 'grey line,' an interplay of favorable factors comes into effect, including

increasing critical frequencies, modest absorption in the D layer, and ionosphere tilting caused by radiation pressure. Furthermore, in the morning, within the terminator belt, the Maximum Usable Frequency (MUF) ascends rapidly, accompanied by more pronounced refractive effects, especially when the gradient undergoes abrupt changes.

MUF

The Maximum Usable Frequency (MUF) is the highest radio frequency that can be used for transmission between two points by reflecting off the ionosphere at a specific time, regardless of the transmitter's power. This index is particularly relevant for our HF transmissions. In HF radiocommunication, one of the primary methods for long-distance propagation is through radio waves reflecting (or not) off the ionized layers of the ionosphere and returning to Earth, not necessarily in a diagonal path. This enables radio waves to travel beyond the horizon and overcome the Earth's curvature. However, it is important to note that the refractive index of the ionosphere decreases as the frequency increases, leading to an upper limit on the frequency that can be utilized. Beyond this frequency, radio waves are not reflected by the ionosphere but instead disperse into space.

Seasonal variations

The ionization of the atmosphere fluctuates with the time of day, season, and solar conditions, resulting in variations in the upper frequency limit for HF communication on an hourly basis. The Maximum Usable Frequency (MUF) represents an average frequency, defined as the highest frequency at which ionospheric communication is possible on 50% of days in a month. In contrast, the Lowest Usable Frequency (LUF) denotes the frequency at which communication is possible for 90% of the days in a month. As a rule, the MUF is approximately three times the critical frequency (Fc). The critical frequency (Fc) corresponds to the highest frequency reflected for a signal that directly

propagates to the ionosphere, considering the angle of incidence (Cosine Ai).

$$MUF = \frac{\text{Critical Frequency Fc}}{\text{Cos Ai}}$$

Focusing effects

When the sun has just risen and the light continues to move westward, the higher altitudes are illuminated first, and the lower altitudes are illuminated later. As a result, near the terminator, a light edge is formed, moving westward with a multi-stratification of layer F, showing an almost parabolic pattern. Along the terminator, we have a parabolic reflector that focuses the signals. This focusing effect is detected by the sudden increase in signal intensity coming from the west, which reaches its maximum value and gradually diminishes as the lighting descends to region D, leading to an increase in opacity. The duration of this phenomenon is shorter for lower frequencies, with a brief yet pronounced peak.

Noise

HF high bands have much lower atmospheric noise than the lower frequency bands because atmospheric noise gradually decreases with frequency, and above 22 MHz, it becomes negligible. On the 10 and 12 meters, with good receivers, you can work with very weak signals that would be impossible to hear on other frequency ranges. At frequencies below 1 MHz, the level of background radio noise picked up by the antenna from the surrounding environment becomes particularly high. The main component of this noise is atmospheric and natural disturbances, which can easily mask the reception of signals of interest. However, the amplitude of these disturbances decreases rapidly as the frequency increases, becoming much less significant in the VHF band.

Eliminating atmospheric-type disturbances, especially those coming from afar, is challenging in HF. These disturbances act like signals and propagate very well through the ionosphere. They are caused by stormy electrical discharges and are subject to wide variations over time, depending on seasonal and daily climatic conditions. Thunderstorms cause RF pulses that propagate in all directions, and since there are hundreds of thunderstorms active simultaneously on Earth, with thousands of electric discharges, their effects can propagate over exceptionally large distances ionospherically. There are two types of noise: local noise caused by local weather conditions, and distant noise. Local noise is recognized as a sequence of very intense impulses spaced over time, while distant noise loses this impulsive feature due to ionospheric propagation and is recognized by a more regular noise pattern. As the frequency increases, noise decreases, and the intensity is higher during the night. This is due to the greater attenuation that noise undergoes during daytime ionospheric propagation. Beyond 10 meters, towards the VHF range, atmospheric noise almost disappears because ionospheric reflection becomes increasingly difficult.

Hypothesis

Let us start to see some anomalies. There is a possibility of a strange phenomenon on high bands, specifically at frequencies above 21 MHz, where one might hear echoes with a delay estimated to be around 300 – 400 ms. This phenomenon could be attributed to "external" reflections from higher layers of the ionosphere, influenced by the Van Allen radiation belts or regions with high ionization caused by the bands that come close to the Earth's atmosphere. These anomalies, situated above the F2 ionospheric layer, could cause reflections and account for the long propagation paths on higher HF bands, allowing certain long-distance connections even with low power. NASA studies have revealed the existence of these irregularities, known as the "South Atlantic Anomaly,"

primarily identified in the South Atlantic region. Additionally, other temporary anomalies might occur due to irregularities in the Earth's magnetic field. While this hypothesis is speculative, it is still worth investigating. The echoes could be a result of signals bouncing multiple times around the world, especially with the influence of the solar cycle, causing them to arrive slightly delayed. Sometimes, the F2 ionospheric region can behave like a massive waveguide, capturing incident beams and causing them to travel great distances before returning to the ground. This phenomenon is more likely to occur during certain conditions, such as when the beams traverse the twilight zone between night and day, where the ionosphere undergoes sudden changes with the appearance of the sun. Similar effects might also be observed for wave trains passing through the area near the North Pole, coinciding with northern auroras, enabling exceptional long-distance connections with very low power. Overall, these anomalies and waveguide effects in the ionosphere contribute to the complex behavior of radio wave propagation in high-frequency bands and require further investigation to fully understand and exploit their potential for communication purposes.

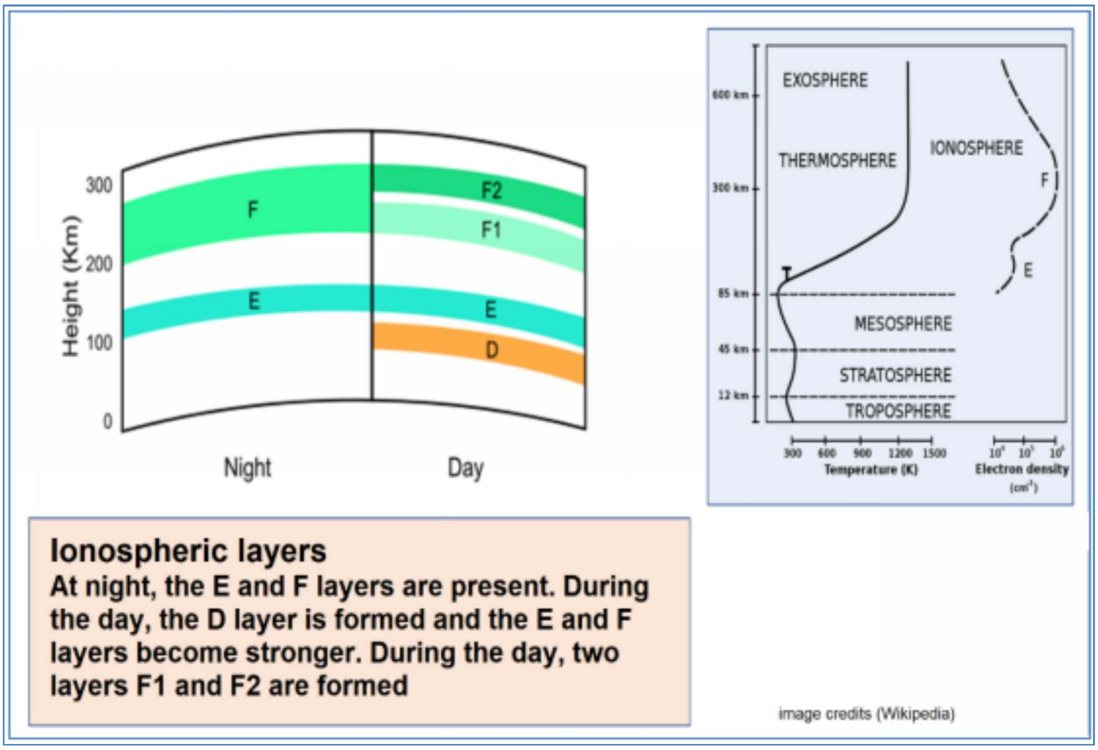
Back scatter

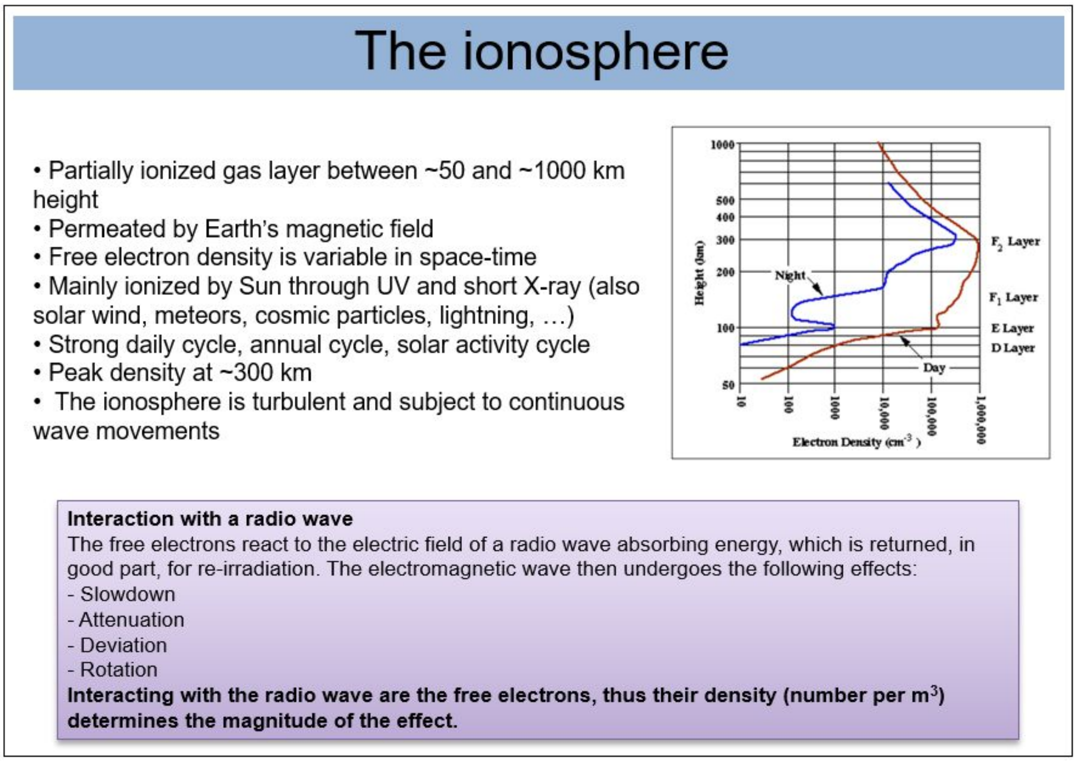
The spread of signals that, after being reflected by an ionospheric layer, return to the ground and scatter in every direction upon contacting the rough terrain is called "backscatter." Due to this phenomenon, it is possible that the Maximum Usable Frequency (MUF) is favorable in a certain direction, directing the signals to a specific area. In such cases, backscatter allows stations to receive signals indirectly by orienting their directional antennas not precisely towards the sender's location, but at a deviation of around 30 or 60 degrees from it. Consequently, the connection is established not through direct pointing but by aligning the antennas of both correspondents with the region where the scattering occurs. Further details on these topics will be explored in the following pages of the book.

Molecular structure of ionospheric layers

The Ionosphere

The ionosphere is the part of the Earth's atmosphere where the sun's radiation, and to a lesser extent cosmic rays from space, cause the ionization of its gases. It extends between 60 and 800 km above sea level, partially belonging to both the mesosphere and the thermosphere. The ionosphere can be further divided into layers, each highlighting distinct electrical properties resulting from changes in composition and the intensity of solar radiation received. Despite its considerable thickness, the ionosphere is extremely rarefied, containing only about 1% of the total atmospheric gas mass.
During the daytime, temperatures in the ionosphere range from 200 K in the inner layers to 1500 K in the outer layers, which are more exposed to the Sun. Solar illumination significantly influences the ionospheric gases, leading to noticeable changes between day and night. Additionally, the longer solar activity cycle also impacts the ionosphere. The ionosphere's unique electrical properties play a vital role in certain radio applications. Under right conditions, an incident radio frequency wave on an ionized layer can be totally reflected due to the electronic saturation of matter. This contrasts with the non-ionized atmosphere, where the refractive index variations are too small to produce total wave reflection, resulting in partial absorption and dispersion of the wave. This characteristic allows for the use of a propagation model based on multiple reflections between the Earth's surface and the ionosphere. Such propagation is particularly efficient for frequencies below 30 MHz, known as short waves, which are commonly used in amateur radio transmissions. (Source: Wikipedia)





D layer

The D layer is the innermost layer of the ionosphere and extends between 60 and 90 km above sea level. It consists

of ionized gas, particularly nitrogen oxide (NO). However, due to the rapid recombination of ions and electrons, the ionization effect is weak. During the day, the ionization is insufficient to support propagation beyond 3 MHz, and at night, the propagation is close to zero. In quiet conditions, this layer is only present during the day. Due to its low ionization intensity, the D layer lacks reflection properties, unlike the upper E and F layers. Instead, it has an opposite effect as it tends to absorb radio waves passing through it, limiting the propagation of medium frequencies (MF) and low high frequencies (HF) over long distances during the day. Only in rare cases, such as during solar flares, the ionization of the D layer can become intense due to X-rays that ionize nitrogen (N2) and oxygen (O2) molecules. This intense ionization can give the D layer significant reflection properties, especially concerning Extremely Low Frequencies (ELF), leading to abrupt changes in the propagation characteristics. These phenomena are known as Sudden Ionospheric Disturbances (SID).

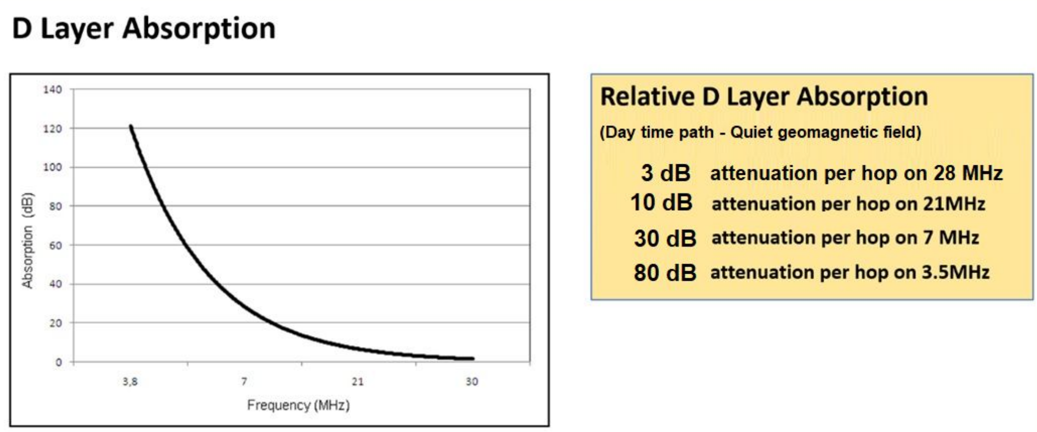


Fig. Relative absorption due to the D layer in HF for daytime paths (Graphic by IK3XTV)

E Layer

The E layer extends between 90 and 130 km above sea level and consists of ionized gas, specifically molecular oxygen (O2). The recombination rate in the E layer is lower than that in the D layer, and some weak ionization remains during the night. It is commonly used for radio

transmissions up to 10 MHz. In calm conditions, there may still be some residual ionization during the night hours.

F Layer

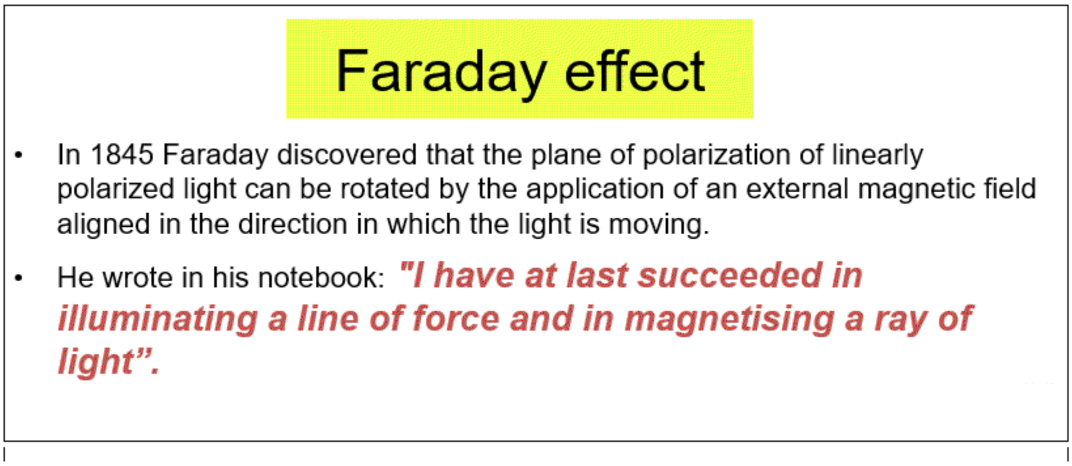
The F layer extends between 130 and 450 km above sea level and is composed of ionized gas, primarily atomic oxygen (O). During the day, the F layer is further divided into two sub-layers, F1 (internal) and F2 (outer), each showing distinct ionization properties. These sub-layers are referred to as "Appleton layers," named after Edward Victor Appleton, who extensively studied them. The F1 layer, which extends up to about 240 km, contains NO^+ ions, while the F2 layer, which extends beyond approximately 240 km, consists of O^+ ions. The F region is of utmost importance for HF communications due to its high electronic density, making it the thickest and most reflective layer of the ionosphere.

Undulations in the Ionosphere

This study focuses on one of the most undesirable characteristics of HF signals, which is the variability of the signal level arriving at the receiver, known as evanescence or fading. The primary contributors to fading of HF signals propagating in the ionosphere are polarization, amplitude variation, and multi-path effects.

Polarization Fading

Polarization fading occurs due to the rotation of the wave's polarization plane in a phenomenon known as Faraday Rotation. For instance, when two waves, an ordinary wave (O) and an extraordinary wave (X), cross the ionosphere with slightly different paths and phase speeds, their circular polarizations, being in opposite directions, result in a wave arriving at the receiver with a different polarization than that of the initial wave. The dynamic nature of the ionosphere causes polarization to change constantly as the wave reaches the evolving receiver, leading to a fading effect.



Evanescence from Multiple Paths:

This type of evanescence occurs when transmitted signals are reflected or refracted by various layers of the ionosphere. Due to differences in path length, the carrier frequency of the signal may change. The Doppler displacement is a result of the motion of electrons within the ionospheric layer, introducing fluctuations in the radio frequency. As the name suggests, multi-path evanescence arises from the existence of multiple propagation paths between the transmitter and the receiver. Waves that travel different paths can interfere constructively or destructively at the receiver, depending on their phase difference. Since the ionosphere is a dynamic medium of propagation, the phase difference between these waves will vary over time, causing the signal to fluctuate at the receiver. The received signal will be the vector sum of all the waves arriving at the receiver. The complex interactions among these waves can lead to variations in signal strength, resulting in evanescence or fading effects during radio communication.

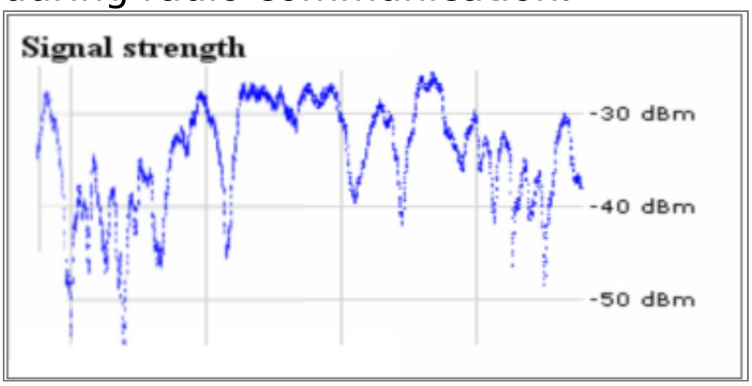
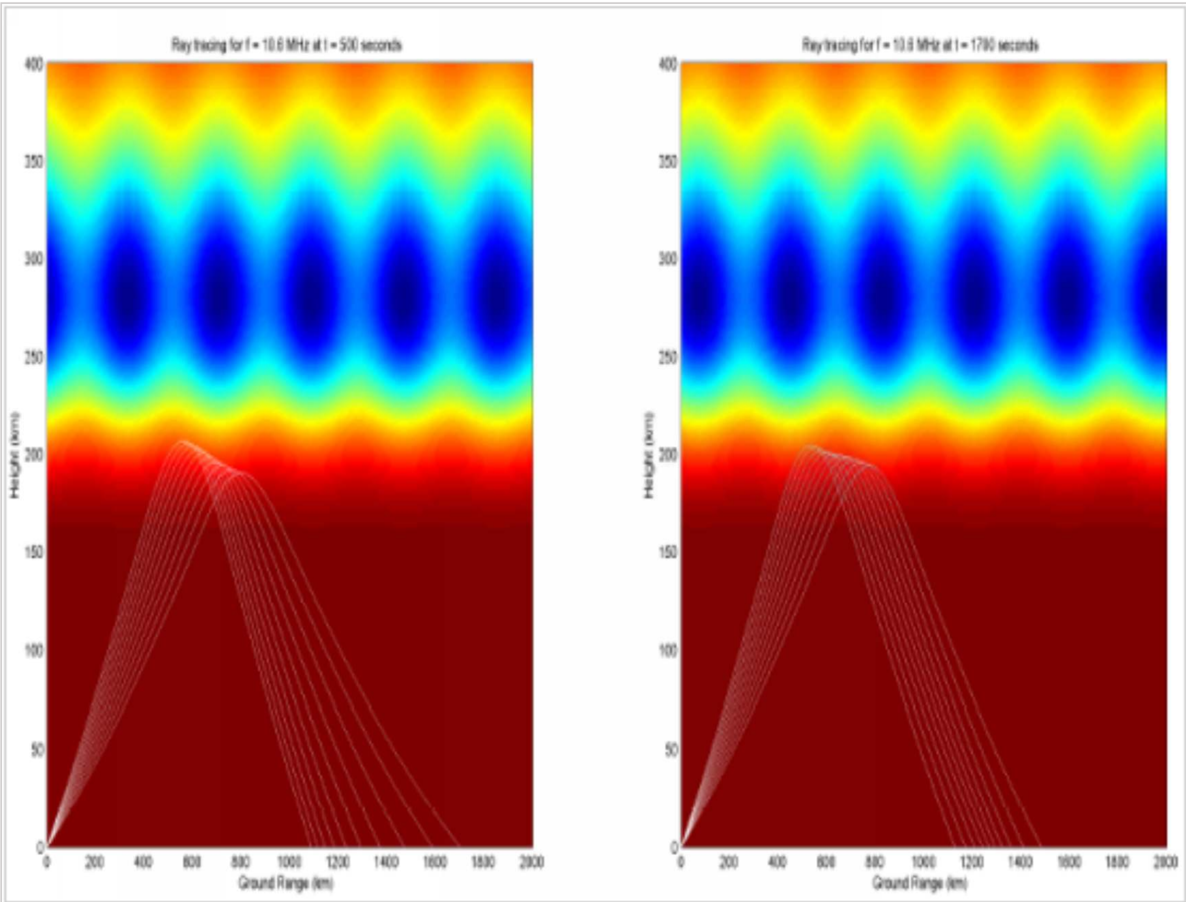


Fig. Evanescence of the signal of Radio China International received in Italy. Fading is power-independent. The big broadcasting transmits with much higher powers than amateur stations, despite this, Radio China's signal has oscillations in the order of 20dBm.
Image credits: Wikipedia.



Another mechanism of variation in signal amplitude

is caused by the movement of large-scale irregularities.

Inside the Ionosphere there are some disturbances, they are called (TID Traveling ionospheric disturbance). Depending on the location of the irregularities, which cause ripple in the ionosphere with the effect that the ionosphere will become concave or convex for the HF radio wave, this causes a focus or defocus on the received signal. These irregularities are constantly moving and cause changes in the intensity of the received signal. These effects are highlighted in the pictured below.

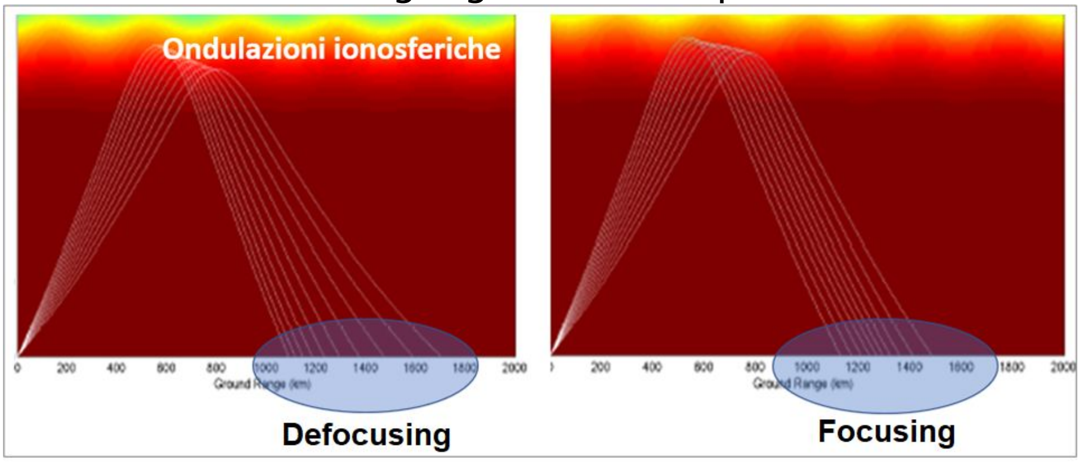
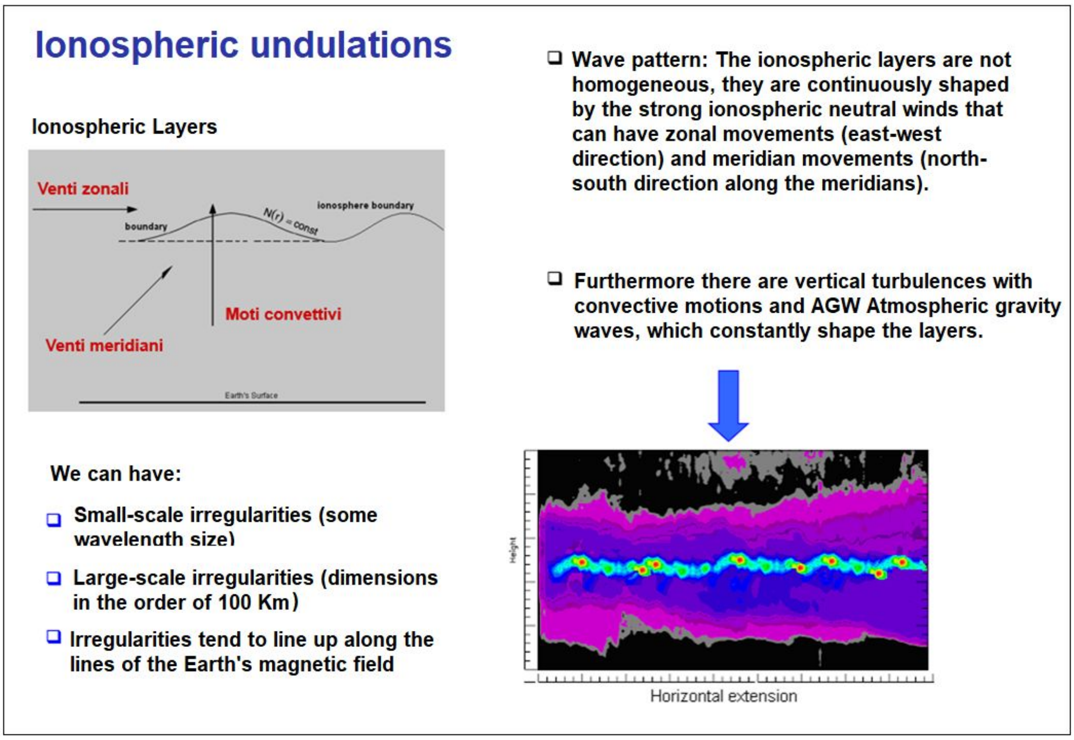


Fig. Representation of medium-scale itinerant ionospheric disorders (TID) and effects on radio waves. An electromagnetic beam is directed towards a receiver located 1220 km from the transmitter. In the image on the left, a defocusing effect is observed, while in the image on the right, a focusing effect is seen on the signal at the ground. (Focusing and defocusing of radio waves due to movement of large-scale ionospheric structure). (Image credits and permission: School of Electrical and Electronic Engineering, The University of Adelaide, South Australia 5005, Australia).

Ionospheric model

Wave model: the ionospheric layers are not homogeneous; they are continuously shaped by strong ionospheric neutral winds that can have zonal movements (east-west

direction) along the parallels and meridian movements (north-south direction along the meridians). In addition, there are vertical turbulences with convective motions and AGW (atmospheric gravitational waves) that constantly shape
the layers. The ionosphere is therefore an "ocean" in continuous movement.



My take on DX: Never give up

These ripples in the ionosphere can have both negative and positive effects on ionospheric communications. If you are struggling to make contact with a DX station, do not give up immediately. Keep trying, as the right opportunity can arise at any moment. The undulations in the ionosphere create phenomena of defocusing and focusing. Eventually, your time to make a successful contact will come too. Focusing can work in your favor, even if you are operating with limited power and modest resources, without a nuclear power plant. Arm yourself with patience, as they say it is the key to success. Sometimes, time and patience can be more valuable than having a lot of power.

The Earth’s Ionosphere from the Space

Recently, has been published some spectacular photos taken by astronauts on the ISS International Space Station (Ref. Science Image NASA Johnson Space Center. From these images it is possible to observe the Earth's ionosphere as a thin green line at a height of about 85 km (D region). This view is possible because of the ionized particles from the solar wind. This is a phenomenon is like the aurora. The most observed color of aurora is green, caused by photons (light) emitted by excited oxygen atoms at wavelengths centered at 0.558 micrometers. Red aurora is generated by the light emitted at a wavelength longer (0.630 micrometers), and other colors like purple or brown are also sometimes observed - the colors depend on the energy of geomagnetic storms, and how high in the atmosphere the impact of oxygen and nitrogen atoms occur.

The Height of ionosphere

I calculated the height of the green light emission that it is at about 85-95 km. (It is in the Ionospheric D region) below those heights the atoms and molecules are more concentrated and collide more readily, releasing their energy sooner, and above that altitude the density of the atoms is too low to do much colliding at all. By summarizing: The region where the glow is visible, is constrained in a height of 85-95 km up in a band about 6- 10km wide. (This Phenomenon is known also as Airglow).

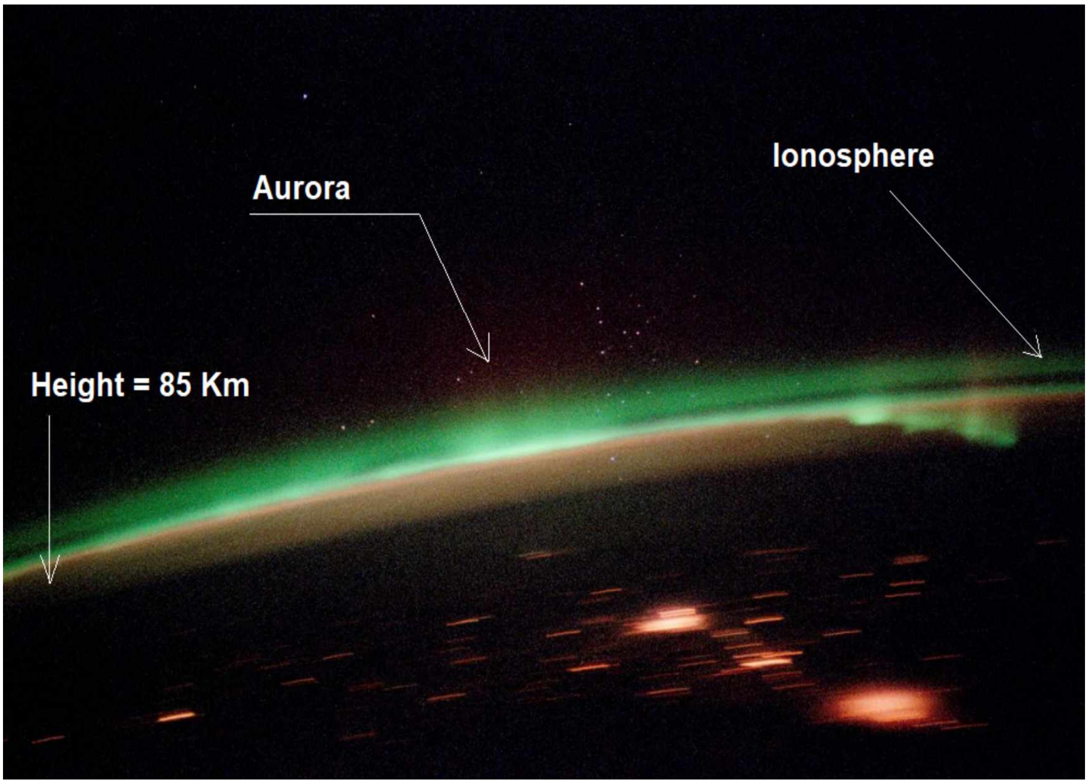


Fig. Green light emission localized in the polar regions (greater intensity, aurora) and extending to the rest of the earth (ionosphere). (Image by NASA from Wikipedia public domain).

What is airglow?

Airglow, also known as "nightglow" or "nighttime halo," is a natural optical phenomenon that occurs in the Earth's atmosphere during the night. It is a faint emission of visible light that originates from the atmosphere itself, rather than celestial objects such as stars or the moon. This light is very dim and usually imperceptible to the naked eye but can be detected by sensitive instruments like long-exposure cameras or spectrometers. Airglow is caused by a series of physical processes in the upper atmosphere of Earth, primarily in the mesosphere and thermosphere. Some of the main causes include:

1. Molecular recombination: At these altitudes, gas molecules in the atmosphere, such as oxygen and nitrogen, can be excited by solar radiation during the day. During the night, these molecules release the accumulated energy in the form of light.

2. Chemical reactions: Some chemical reactions in the nighttime atmosphere can produce light, such as the oxidation of sodium atoms by molecular oxygen.

3. Excitation from cosmic radiation: High-energy particles from outer space, like cosmic rays, can collide with atmospheric molecules and trigger processes that produce light.

Airglow is one of the reasons why the nighttime sky is not completely dark. Even in the absence of artificial light or sources of celestial light, airglow contributes to creating a faint background illumination in the nighttime atmosphere. However, to see airglow in all its splendor, it is often necessary to use sensitive instruments in low-light conditions or in remote locations far from the light pollution of cities.

Description

Airglow arises from a variety of processes in the upper atmosphere. In daylight, ions become photoionized by the Sun, and their recombination during the night gives rise to airglow. Luminescence occurs because of cosmic rays colliding with the upper atmosphere, while chemiluminescence primarily arises from the interaction between oxygen and nitrogen with hydroxyl ions at altitudes several hundred kilometers above the Earth's surface. The scattered sunlight during the day makes airglow imperceptible. Airglow imposes limitations on the sensitivity of ground-based telescopes at visible wavelengths, even at top-tier observatories. Consequently, space-based telescopes such as the Hubble Space Telescope can observe fainter objects in visible wavelengths compared to their terrestrial counterparts. During the night, airglow can become sufficiently bright to be visible, often exhibiting a bluish hue. However, its brightness is most pronounced when observed at an elevation of around 10 degrees above the horizon. As one's line of sight descends, the thickness of the observed atmosphere increases, leading to a reduction in apparent brightness due to atmospheric extinction. The mechanism underlying airglow entails the combination of nitrogen and oxygen atoms to form nitric oxide (NO) molecules, releasing photons in the process. The dissociation of nitrogen (N2) and oxygen (O2) molecules by solar energy in the upper atmosphere yields free atoms that can subsequently combine to create NO molecules. Other atmospheric species, such as hydroxyl (OH), molecular oxygen (O), sodium (Na), and lithium (Li), can also contribute to airglow, with sodium playing a role in the formation of the Sodium layer. Sky brightness is typically quantified in units of astronomical magnitudes per square arcsecond of the sky.

Observations about the trans-equatorial grey line

One of the most favorable moments for long-distance communications in the short waves is at sunrise and sunset, with interesting implications for the Earth's ionosphere. The grey line is that line (it is also called the terminator) that divides the dark part of the globe from the one still illuminated by the sun. This area is also called the twilight belt and has a width of approximately 1200 – 1500 km and moves progressively westward following the Earth's rotation. The inclination of this "grey line" varies following the trend of the seasons.

The dynamics of the MUF (Maximum usable frequency) near the terminator

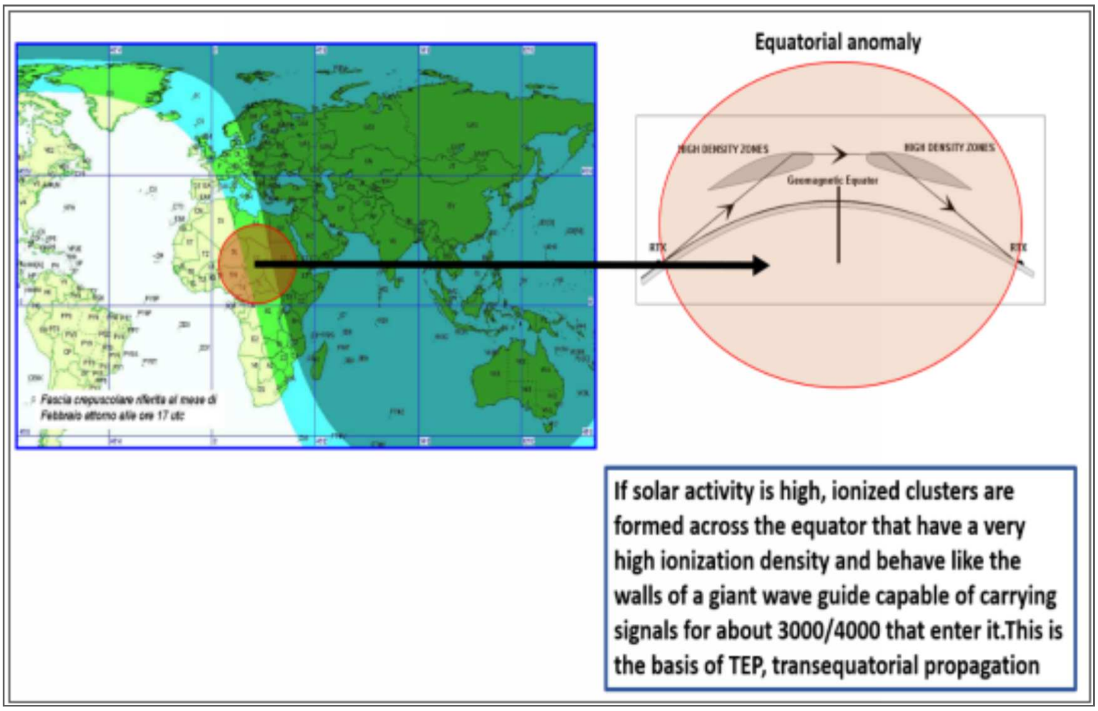
It is the lowest part of the ionosphere between 70 and 90 km above altitude and has the lowest ionization density, it is present only in the sunlit part. It has the negative effect of attenuating the waves that pass through it, especially those with lower frequency. At dusk, a rapid degradation of layer D occurs, by recombination, positively influencing the conditions of propagation of electromagnetic waves. In the illuminated part of the globe, we find the highest MUF of the day, vice versa we find lower MUF on the dark side. MUF rises rapidly as the sun radiates the Earth's ionosphere and slowly decreases with darkness, while region D forms slowly as the sun rises but degrades very quickly just after sunset. On the grey line, there are therefore a sum of favorable factors such as increasing critical frequencies, absorption of the still mild D layer, radiation pressure that tilts the ionosphere. In the terminator belt, MUF moves very quickly, and refractories are more marked just when the gradient changes abruptly.
Therefore, for a period depending on the frequency, there are favorable conditions for searching for the connection over long distances. On the high bands (14 –18 – 21 MHz), this period can vary from one to two hours, while it is lower in the lower frequencies, although for the latter, the twilight propagation plays a more key role, especially due to the greater influence of the D layer. As you go down with the frequency, in fact, the D layer takes on an increasingly determined role.

Let us look at what is going on.

Although we are already in darkness, the F layer is still ionized because, being higher, it remains illuminated for a longer time by the sun, and the decay process is slow. In the lower layers, including layer D, ionization decays very rapidly, and therefore, the absorption introduced from the lower layers of the ionosphere becomes increasingly mild. As soon as the sun sets, the lower layers are still partially ionized, creating an ionization gradient, low enough to attenuate the signal but high enough to reflect it and then lower its angle by progressively bending it and sliding it along the top F layer. This creates something like an ionospheric duct that takes the signal up to the corresponding point without intermediate bounces. However, the process takes little time as the sun continues to move westward, with the result that the ionization of the F layer begins to decrease, the lower layers disappear altogether, and the favorable mechanism decays rapidly. Under these conditions, the DX signals first begin to fade and then disappear.

Trans equatorial anomaly

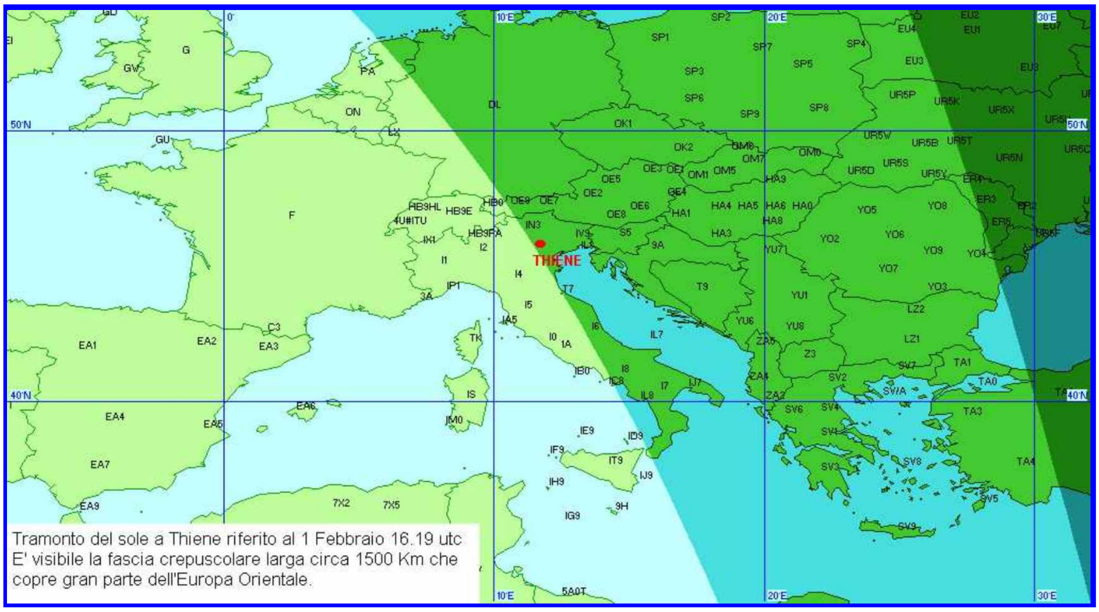
One of the most interesting features of the tropical ionosphere is the equatorial anomaly, which consists of the fact that in areas between 20 and 30 degrees, both north and south of the geomagnetic equator, the influence of the sun on the electronic concentration of the ionosphere is noticeably different from what is expected. Solar radiation, especially ultraviolet rays, causes an extraordinarily strong ionization of the ionosphere, resulting in a large electronic density in the tropical region and many free electrons caused by the solar wind. These electrons align along the force lines of the Earth's magnetic field, forming cigar masses aligned according to the geomagnetic field (figure below). If solar activity is high, these formed cigar masses have a higher ionization density than the normal ionosphere and behave like the walls of a giant waveguide capable of deflecting signals for about 3,000 to 4,000 kilometers, surmounting the equator. The discontinuities present in these edges allow the wave trains to enter and exit the guide. TEP (Trans Equatorial Propagation) uses this phenomenon. We will return to this topic later in the part of the book dedicated to trans equatorial propagation on 144 MHz.



My experiences with trans-equatorial grey line

For a period from October to March, the grey line is positioned longitudinally to have favorable conditions with South Africa, and with some other countries such as Zambia, Namibia, Botswana, Zimbabwe, located over the equator.

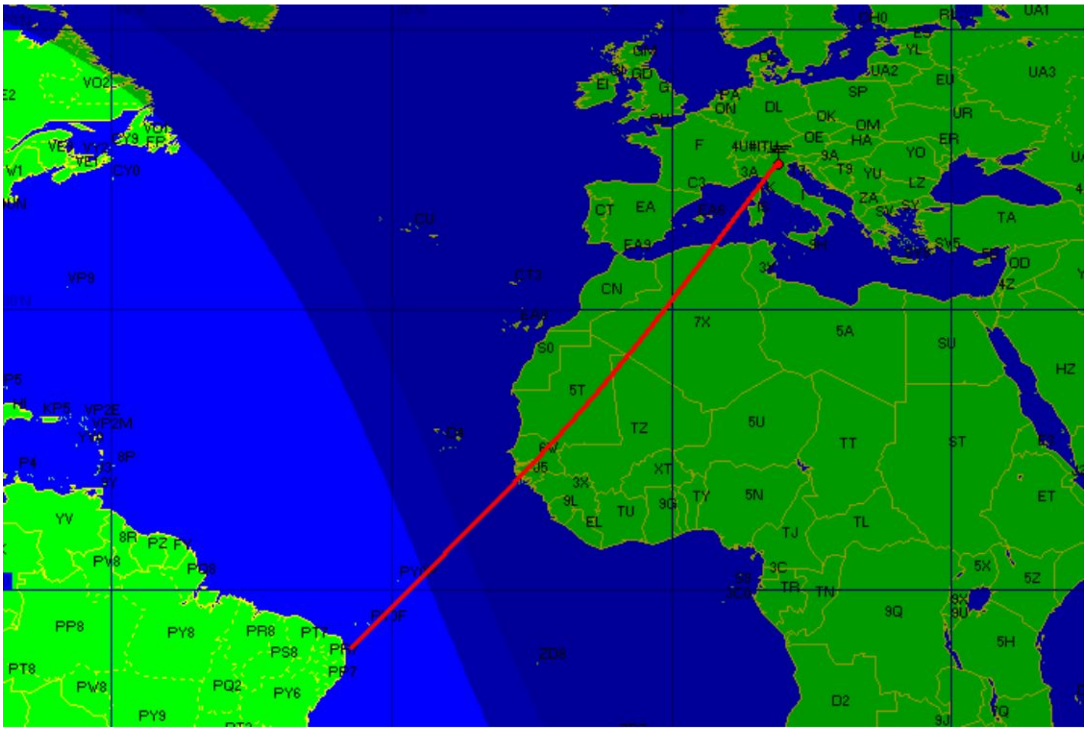
I have evaluated this opportunity on various occasions, connecting with and listening to many stations located in this area of the world, below the equator. Taking advantage of this favorable moment, you can easily work with stations, even with modest antennas and low power. You must look for the grey line and wait for the right moment. Do not give up if they do not answer you on the first attempt, especially if you are not working with high power. You must be patient, especially in these paths, as fading is always a possibility. Remember that the ionosphere is constantly changing, and conditions continue to vary. Eventually, the right time will come. If your station is small, you need to make the most of the positive spike of propagation.



Map created using the DX Atlas software, www.dxatlas.com.

The trans-equatorial towards South America

On Wednesday, December 4, 2002, at 19:00 UTC, the high bands, including 20 meters, seem completely closed. I start listening to the beacons of the NCDX Foundation, there is an absolute silence. I am checking the MUF and I see they have dropped below 10 Mhz. At one point, on the frequency of 14230 KHz, at 7.36 pm UTC I listen to a strong signal S9+10dB, when suddenly, out of nowhere and with much fading, I received the station PY7XC from the Island of Itamaraca (Iota SA-046) located in the Ocean near the coast off Recife. PY7XC was calling CQ, but no one answers him. A little surprised, I immediately respond to his call and easily I establish the bilateral connection, with the other side of the Atlantic. Miracles and mysteries of propagation. I made a QSO that was theoretically impossible on the paper. But often reality is different from the paper theory and one of the most fascinating things about radiantism is precisely the possibility of these surprises and extreme and almost impossible contacts.



But what made this QSO possible?

Map created using the DX Atlas software, www.dxatlas.com.

Hypothesis

The link was caused by the combined effect of the equatorial anomaly and grey line, positioned above the Atlantic Ocean, straddling the geomagnetic equator. The PY7XC signal may have entered in the wave guide that forms above the geomagnetic equator, induced by equatorial radiation pressure and then conveyed for a series of multiple reflections, over Europe, taking advantage of the residual ionizations of the E region. The signal was subject to severe evanescence due to multiple reflections caused by the passage into the equatorial anomaly, where cigar clusters form electrons are in continuous motion due to the different pressure of solar radiation, such as the illuminated area and the area in darkness. The magnetic field was quiet, and as we know this is an important condition for the dynamics of propagation, in general. The K index at 18 UTC was at 3 and although activity was increasing, reaching a value of K4 at 20:00 UTC, the perturbation effects of the geomagnetic field, at low latitudes are delayed.

Residual ionization of E layer.

I believe that the residual ionization of E layer, which as we know is gradually decreasing after sunset, is important for the dynamics of many contacts. The level of ionization, compared with the degree of opacity relative to a given frequency (we know that the reflection capacity of E layer increases as the frequency decreases), plays a key role in the diffusion of signals, because it is lower than the F region. Waveguides can be formed between E layer and F layer, capable of conveying signals at great distances, between ionosphere-earth-ionosphere. Combined effects between the various ionospheric regions with different ionization gradients occur much more often than one might think. Otherwise, the QSO made for example by very low power stations would not be explained, where the sum of the losses and attenuations would make impossible on paper for the QSO, even when MUF maps show that it is impossible. How many times has it happened to you not to hear a station a few kilometers away and to hear a station at 9 + 20 dB a station for example from Indonesia?

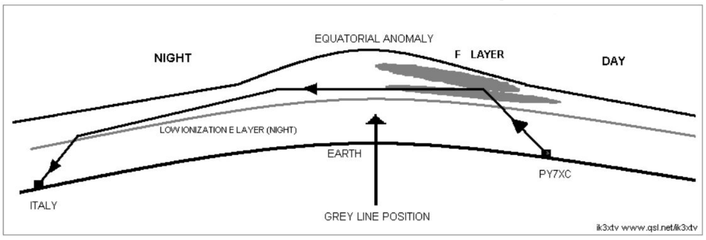
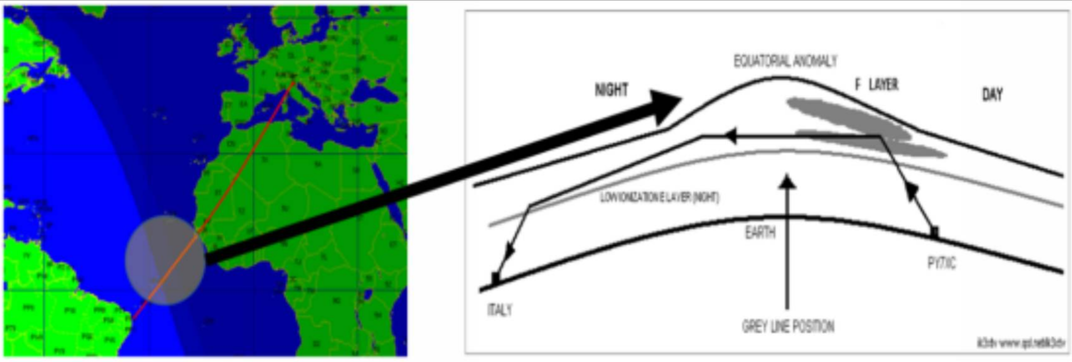
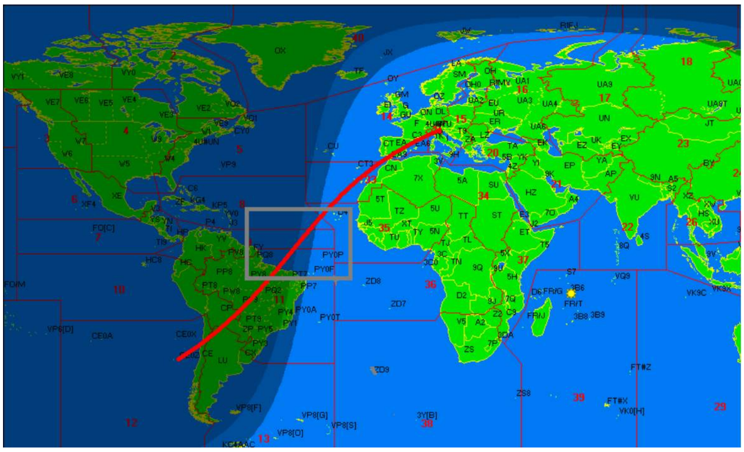


Fig this is the way of how the QSO with PY7XC could have happened. The signal exploited the equatorial anomaly, the irregularities in the ionization gradient in the equatorial anomaly, amplified by the presence of the terminator at that time straddling the geomagnetic equator.



Equatorial anomaly over the Atlantic
It allows frequent evening propagation openings for South America, on bands above 20 meters

QSO with the South Pacific: Robinson Crusoe Island- CE0ZIS station



Map created using the DX Atlas software, www.dxatlas.com.

Saturday, October 19, 2002. It is a beautiful sunny day outside, but I still sit in front of my radio. I decided to listen to the 17 meter band for a while. I began calling CQ with the antenna beaming north but received no replies. However, around 9 a.m. local time, I suddenly heard a tremendous pile-up at 18.138 MHz. This intense activity was caused by CE0ZIS, Eliazar, operating from the Juan Fernandez archipelago, specifically from Robinson Crusoe Island in the South Pacific, found approximately 12,650 kilometers away from my location. This island was made famous by the story of sailor Alexander Selkirk, whose adventures there inspired Daniel Defoe's novel, *"Robinson Crusoe."* The whole experience felt quite romantic, reminiscent of the adventurous atmosphere of the novel. After several attempts, I finally managed to break through the pile-up and establish a connection with Eliazar. He was receiving calls from Europe and Japan, but the propagation to North America appeared to be closed for him as it was in total darkness. This DX connection to the South Pacific was particularly interesting, and I attributed it to the trans-equatorial propagation towards South America, once again involving the grey line and the equatorial anomaly. These elements always prove to be helpful "friends" in our radio pursuits. The Equatorial Anomaly met in the north-south path, like the classic one between Italy and South Africa, played a role in this connection as well. The signal from CE0ZIS arrived at an S7 strength level, but it experienced significant fading due to the passage of wave trains straddling the magnetic equator. The motion and disorder of the cigar clusters caused continuous variations in the refractive index, leading to the fading effect.

The contribution of EME (Earth-Moon-Earth) in the ionospheric studies

In this section of the book dedicated to EME propagation, edited with the valuable collaboration of Giorgio Marchi, IK1UWL, we will explore various research related to the influence of the ionosphere on signals passing through it (Trans-ionospheric propagation). EME signals bound for the moon must traverse the Earth's ionosphere. By studying the effect of the ionosphere on the phase and amplitude variation of the signal, we saw that the amplitude of the signals after the double crossing had an almost periodic fluctuation, as described below. We conducted these studies using Joe Taylor's MAP 65 system software. MAP65 is a computer program designed for EME communications using the JT65 protocol. The program is used with an RF system that provides two consistent channels for two orthogonal polarizations: horizontal and vertical. This software automatically allows reception with the right polarization, as the two polarizations are managed simultaneously through a mathematical algorithm. Consequently, the change in signal amplitude is free from the Faraday effect.
This is what we have observed:

- We always see a fluctuation of S/N signal levels in decoding.
- We notice a long-term fluctuation with associated shorter fluctuations.
- We believe that fluctuations are caused by focusing/defocusing effects caused by ionosphere ripple.
- Given the magnitude (3-5 dB) there they cannot be attenuations related to the thickening of the ionospheric,

caused by the undulations.

Winds and ionospheric waves

Typically, in the ionosphere there are winds of 100-500 m/s, forming waves and vortexes (TIDs).
In the typical wind of 200 m/s = 12 km/min. they correspond to waves of length 1000-1500 km on which smaller waves of length of about 100 km overlap.

The undulation of the layers of E sporadic

The plasma forming the layers of sporadic E is also not uniform but has undulations modulated by the action of ionospheric winds and atmospheric gravity waves (see Note 1). The layers are never flat but can have wavy structures and in some cases even domes.

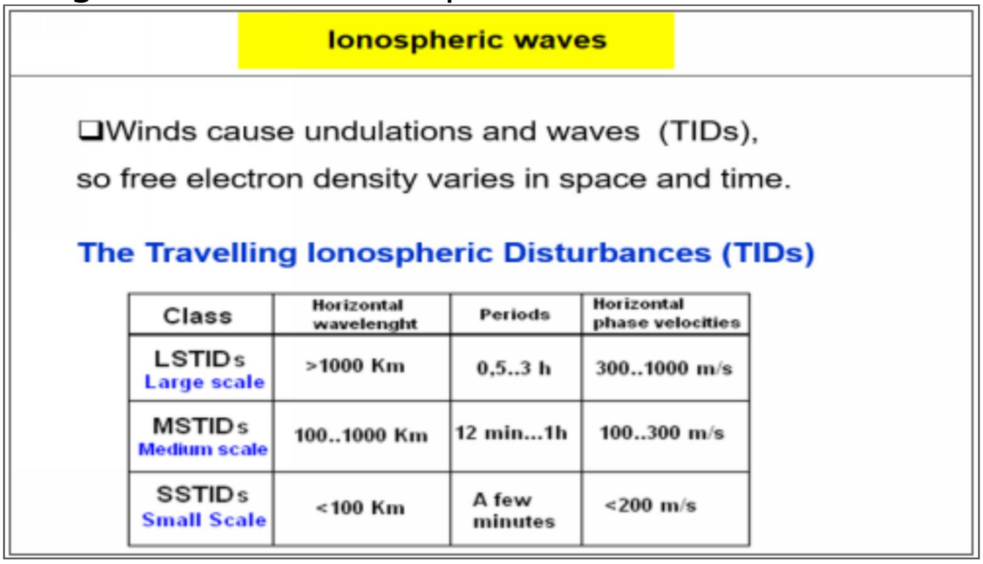
Fig. Domed shaped clouds by atmospheric winds and gravitational waves. (Photo IK3XTV).

Note:

1- Atmospheric gravity waves (AGW)
Atmospheric gravity waves are elastic oscillations that propagate into the atmosphere because of its thermal stratification. The wavelength ranges from a few hundred meters to hundreds of kilometers, with periods ranging from a few minutes to a few hours. The resulting air oscillations cause small fluctuations in atmospheric variables (pressure, temperature, humidity...) but they have a significant impact on the structure of the Ionosphere. In recent years, scientific research on the Ionosphere and radio propagation has given great prominence to the role of gravitational waves in that they play a decisive role in the structure of the Ionosphere and therefore in the propagation of radio waves. AGW, interact with the Formation of sporadic E - Tropospheric propagation - influence on F region - Ionospheric disorders - Ionospheric absorption in the D Region - Massing/displacement of ions inside the Ionosphere. The influence of AGW seems more marked in the formation of the night F2 layer, where they would help to supply a small but continuous source of new ionization, contributing to the maintenance of residual night ionization.

2. TID Multipath fading is caused by the presence of different signal paths and therefore signal arrival delays between the transmitter and the receiver. Waves coming from these different paths can interfere constructively or destructively depending on the phase difference at the receiving point. Due to the dynamic nature of the ionosphere, the phase difference between the different waves will vary over time and thus cause evanescence. When the ionosphere is disturbed, the many reflective points can produce time-varying evanescencies with periods ranging from a few seconds to tens of seconds, depending on the scale of irregularities. There is another

factor that induces fading, due to the focusing effects due to the movement of large scale (LS) irregularities that produce slower fading, in order of tens of seconds. In fact, the movement of LS irregularities in the ionosphere causes a decrease in amplitude unlike the variability of phase interference and the location and shape of irregularities, the ionosphere acts as a mirror for HF waves. When radio waves are reflected from a concave surface of ISO density, the waves will undergo a focus gain; conversely, when the surface is convex, there is a loss by blur effect. The table below shows the scale of irregularities with the phenomena associated with them.



Ionospheric waves

❑Winds cause undulations and waves (TIDs), so free electron density varies in space and time.

The Travelling Ionospheric Disturbances (TIDs)

Class	Horizontal wavelenght	Periods	Horizontal phase velocities
LSTIDs Large scale	>1000 Km	0,5..3 h	300..1000 m/s
MSTIDs Medium scale	100..1000 Km	12 min...1h	100..300 m/s
SSTIDs Small Scale	<100 Km	A few minutes	<200 m/s

Ionospheric undulation in trans ionospheric propagation

Signals that must cross the ionosphere twice, such as those signals transmitted to the Moon and Reflected, as in the case of the EME, could be focused/de focused, as they cross the Ionosphere. (Interaction could take place in two ways). On earth there are areas of fading and because of focus/de focus effects. Ionospheric irregularities can be seen as a filter that introduces instability in EME signals and is like scintillation phenomenon, which occurs in trans ionospheric communications, as in the case of signals from satellites.

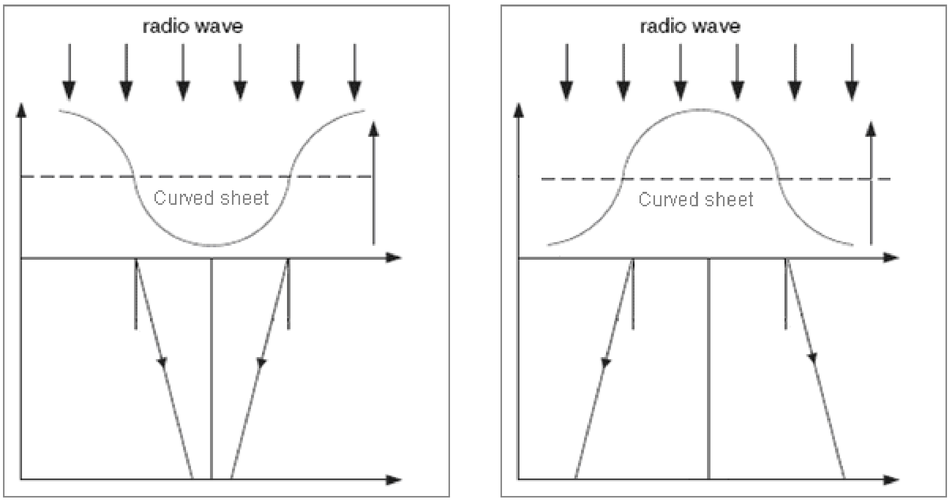


Fig. Model of penetration of radio waves through a sine-shaped ionospheric layer. A radius passing through a curved structure, changes the trajectory of its path. We have a phenomenon of focus or de focusing, depending on the shape of the irregularities (concave / convex).

Ionospheric fluctuation

The effect of TID on the ionosphere, we have seen it by looking at EME signals, which also help us to understand the behavior of the ionosphere for HF frequencies. After we did so many observations and recording on the instability of EME signals, we tried to correlate this Ripple that is always present on the EME signals with the turbulence of the ionosphere. Let us first define the type of Ripple. They are shown below, a couple of real cases with recording signals with seamless decoding every 2 minutes. On rather long reception periods. The charts show the reception of the signal emitted by a Russian EME station RX1AS, received by PA3FPQ in Netherland.

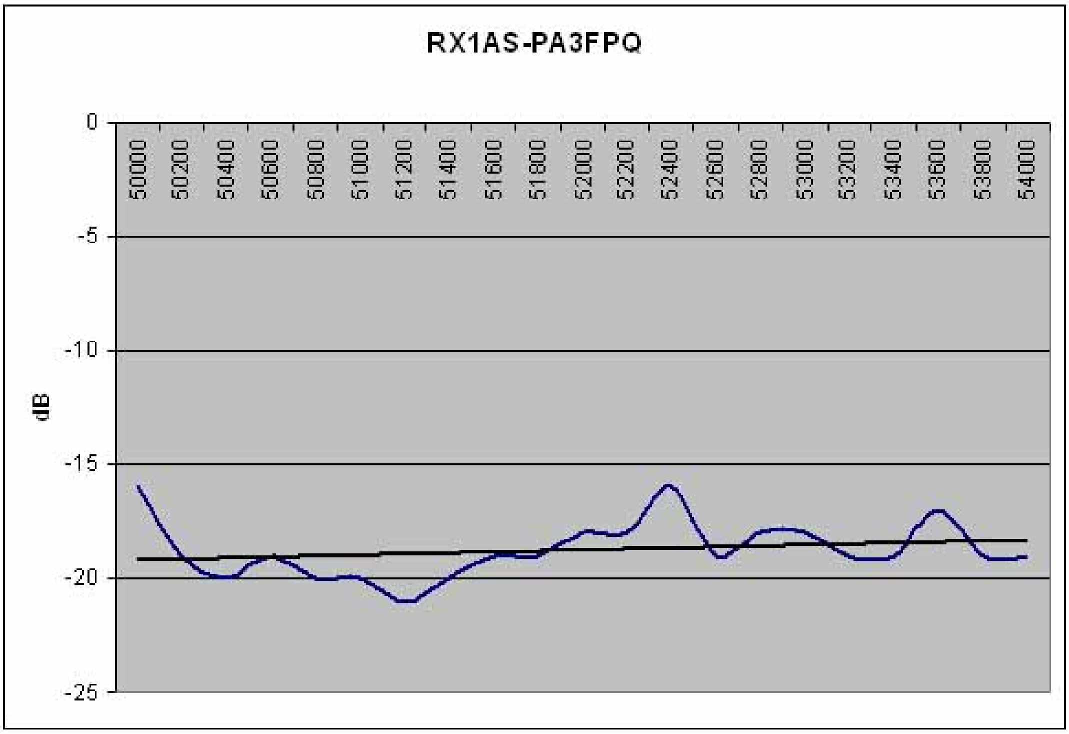


Fig. EME signal transmitted by RX1AS and received by PA3FPQ. The fluctuation was equal to 5dB, from -21 dB to -16 dB and you can see both periods of 4 minutes and period of 24 minutes.

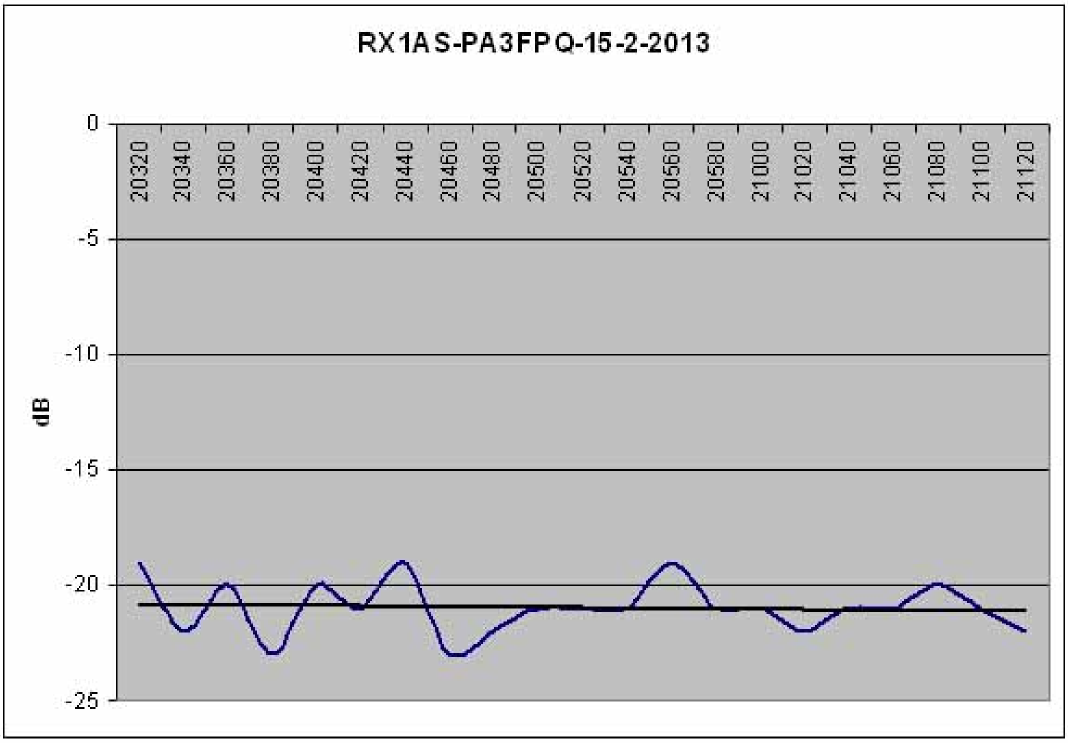


Fig. Another registration on another date. The fluctuation was from -19 to -23 dB and periods of both 4 minutes and 12 minutes are noted. As in rough seas, we see short waves superimposed on longer waves. We know that zonal ionospheric winds have speeds of the order of 50-100 m/s.

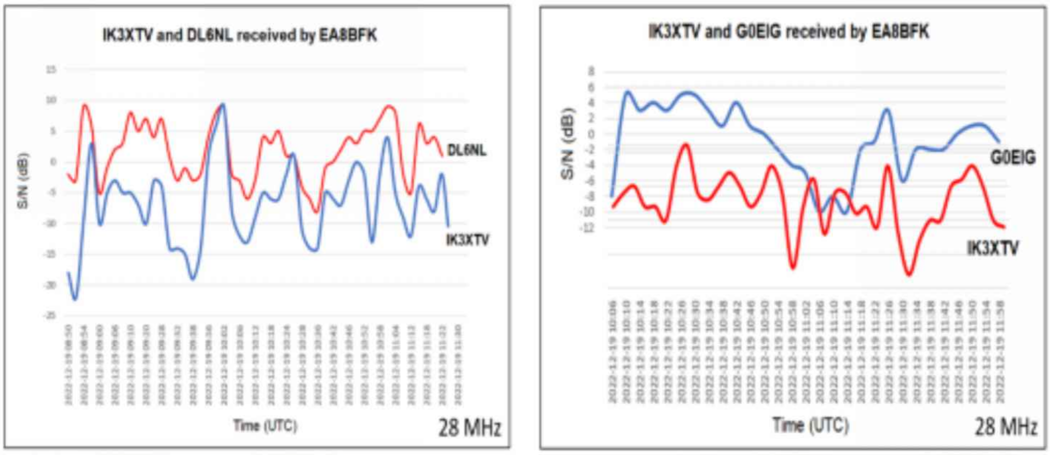
We know that in the ionosphere there are mobile disturbance, called TIDs. Let us review them in a brief:

Polarization fading occurs due to the rotation of the wave polarization plane, a process known as the Faraday rotation. Two characteristic waves, the ordinary (O) and the extraordinary (X), cross the ionosphere with a slightly different path and phase velocity, since they are circularly polarized and in the opposite direction, the resulting wave arriving at the receiver will have a different polarization than that of the initial wave. The dynamic nature of the ionosphere causes the constantly evolving polarization of the wave arriving at the receiver, resulting in fading effects. Another fading mechanism is amplitude fading, which is caused by the movement of large-scale irregularities in the ionosphere. Depending on the location of the irregularities, the ionosphere will effectively become a concave or convex reflection layer for HF radio waves, which causes focusing or defocusing effects on the received signal. In these graphs, the two phenomena we are dealing, are perfectly described and summarized.
Staying on the levels. In addition to zonal winds, we know that TIDs have wavelengths from 100 to 1000 Km and speeds of 1000 m/s. We can deduce that in general a wind of 100 m/s produces waves of wavelength of 1000 Km in the ionosphere. (100 m / sec = 6 km / min. = 24 km / 4min = 72 km / 12min = 144 km / 24min) The periods of 4 ', 12' and 24 'observed in the two graphs seem to be related to the passage of waves with length waveforms of 24, 72, 144 km, superimposed on each other.
They are the same values that are given for the TIDs and represent a situation of wave motion like what we see on the sea, scaled by the different density.

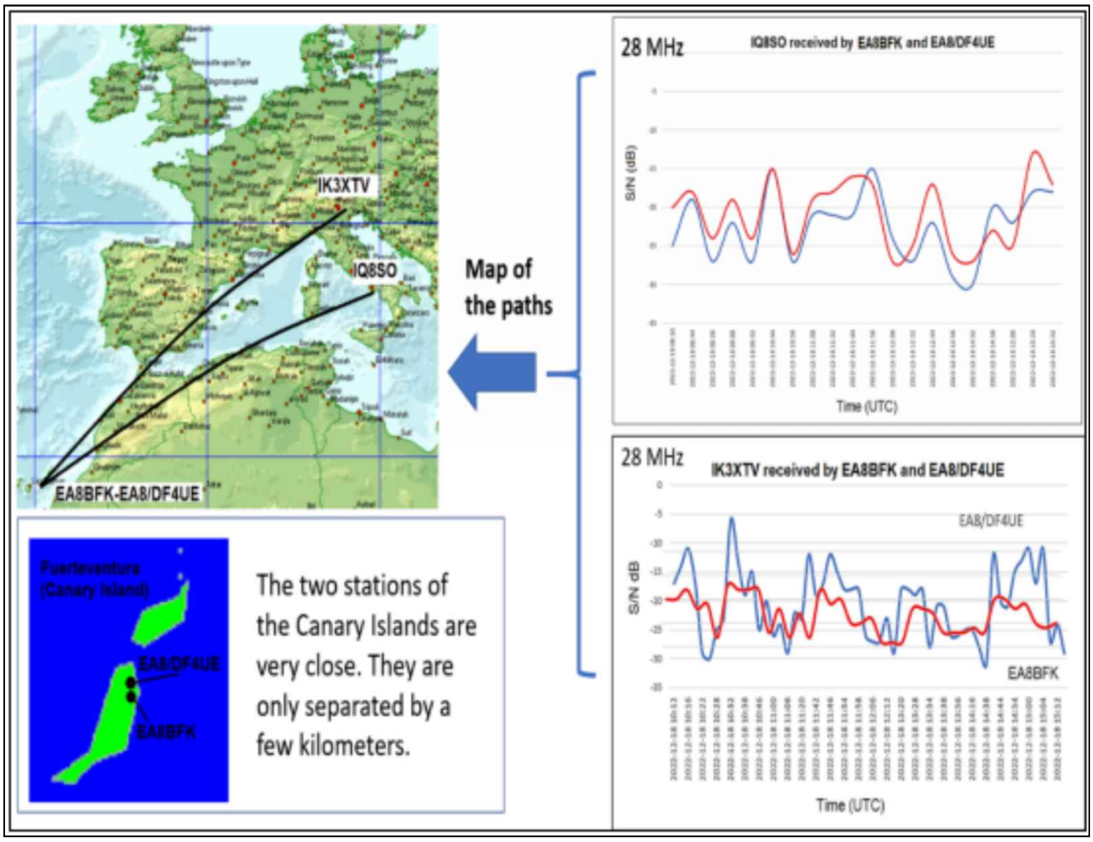
NOTE: We will review these topics better and with more detail in the chapters dedicated to EME propagation.

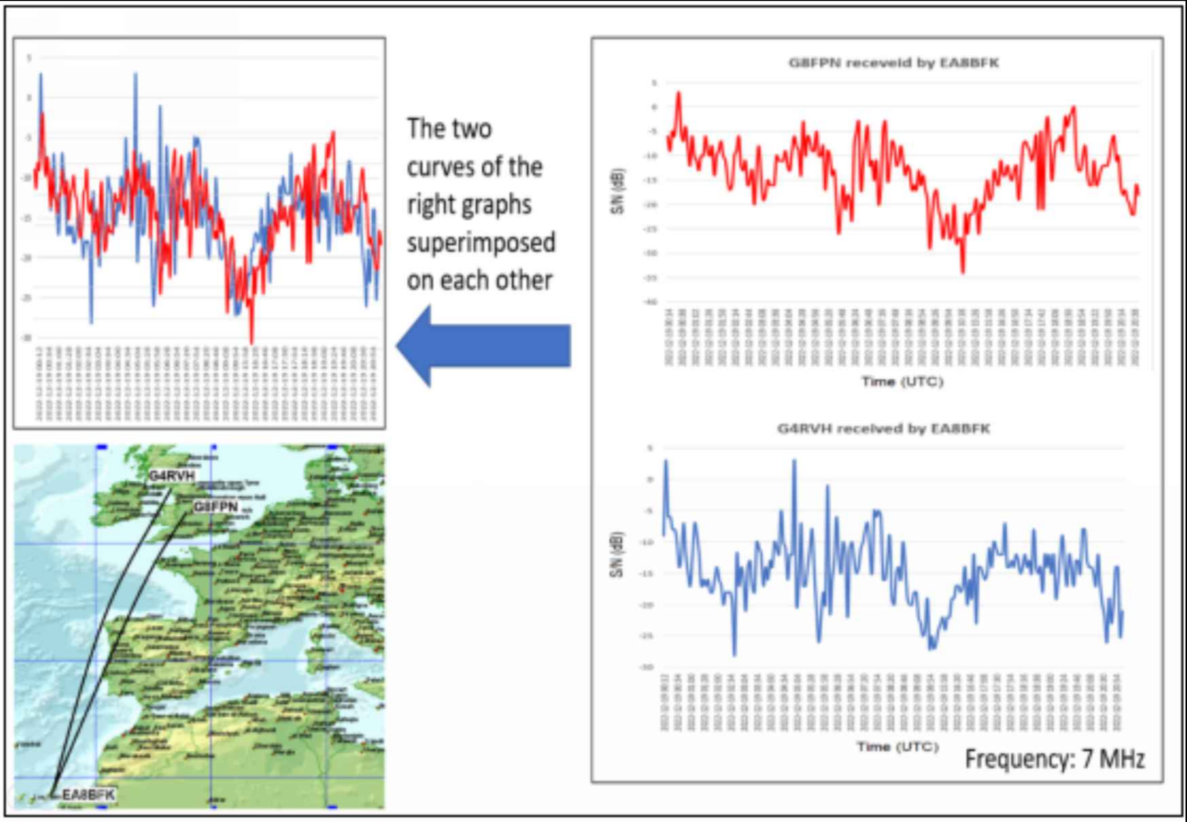
The behavior of the ionospheric path is the same for all

Despite all the studies and research I have conducted, the ionosphere always remains mysterious to me. This is precisely the reason for its great charm. However, one thing I have noticed is that the ionosphere is democratic in its behavior. One aspect that has always bothered me during my radio activity is fading, which often limits and penalizes listening, especially when the signals are not strong. Sometimes the signal disappears entirely, only to suddenly reappear. Being a radio amateur requires patience, as we meet large oscillations in signal strength, sometimes exceeding 20 dB.
To thoroughly study the phenomenon of ionospheric fading, I used the WSPR software along with my beacon, transmitting at extremely low power. The WSPRnet program, combined with a database on the web, proved to be an indispensable tool for this study. My goal was to check if fading is symmetrical and if it affects all stations equally. I wanted to understand how the ionosphere behaves in such situations. To achieve this, I adopted the scientific method, following the path Galileo pointed out. The experiment involved using my WSPR beacon and logging the signals received from a few stations, plotting the data on a graph. I then compared this data with that from other stations to see if the signal on the same ionospheric path changed or remained consistent. Experiments like this have become possible thanks to digital technologies, such as the WSPR beacon system and the WSPR propagation reporter system. They have opened new ways for investigating and understanding the behavior of the ionosphere during fading conditions.

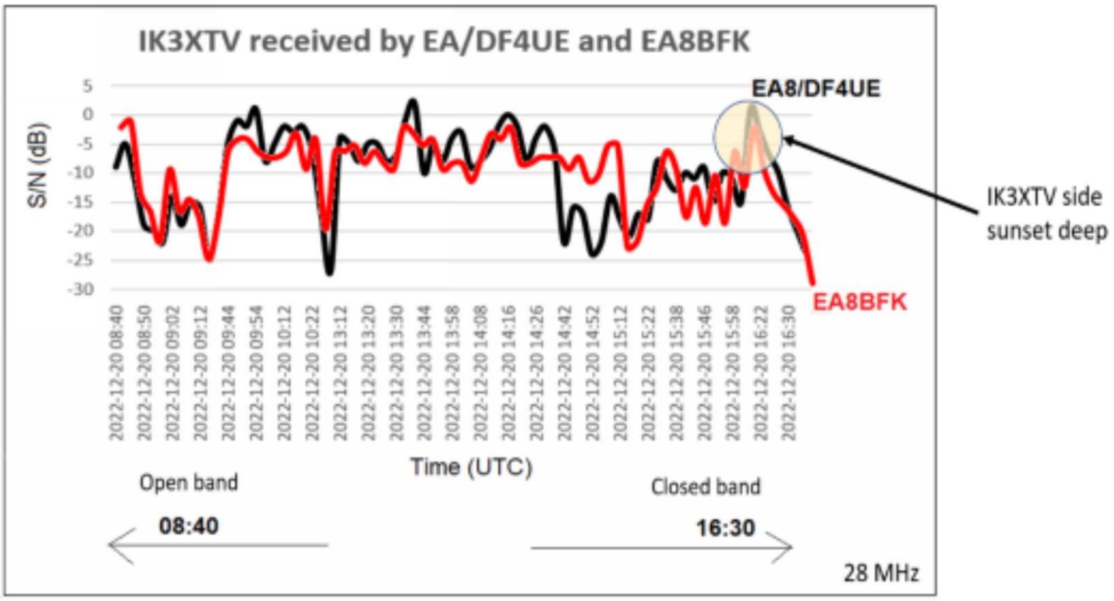


The trend of the left graph curves are very similar. When the path is very different, the correspondence between the two curves decreases, as seen in the graph on the right.

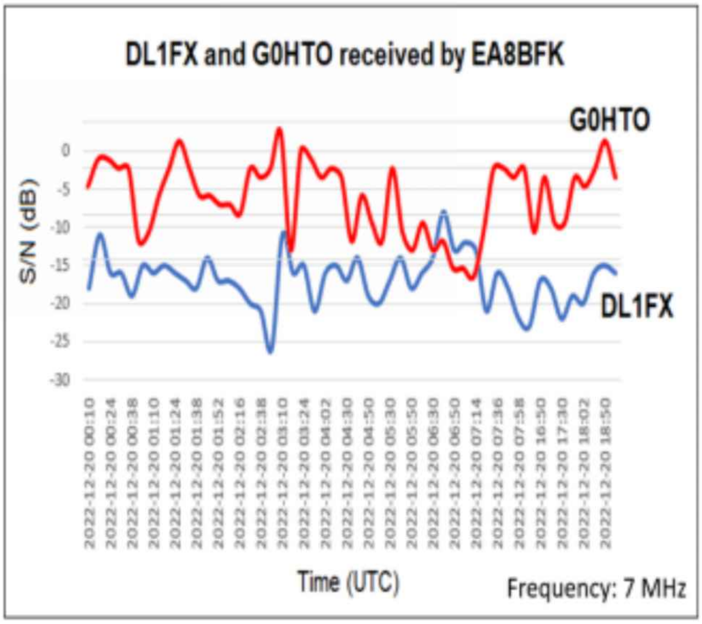

IK3XTV
IQ8SO
EA8BFK-EA8/DF4UE
Map of the paths
Fuerteventura (Canary Island)
EA8/DF4UE
EA8BFK
The two stations of the Canary Islands are very close. They are only separated by a few kilometers.
28 MHz
IQ8SO received by EA8BFK and EA8/DF4UE
S/N (dB)
Time (UTC)
28 MHz
IK3XTV received by EA8BFK and EA8/DF4UE
S/N dB
0
-5
-10
-15
-20
-25
-30
-35
EA8/DF4UE
EA8BFK
Time (UTC)



Full day reception of my WSPR beacon IK3XTV received by two stations from the Canary Islands EA8/DF4UE and EA8BFK. The two signal curves have been superimposed on the same graph and show almost perfectly the same shape.

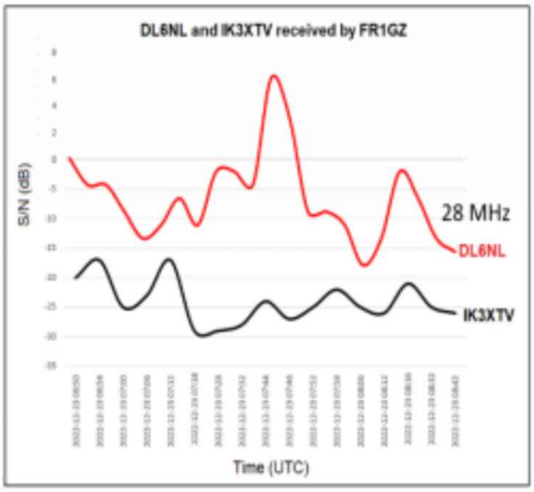


The distance between G0HTO and DL1FX is approximately 1200 chilometers and the path is completely different. The result is that the signal trend curves are very different. The profile of ionosphere and TEC in this very large area is different.

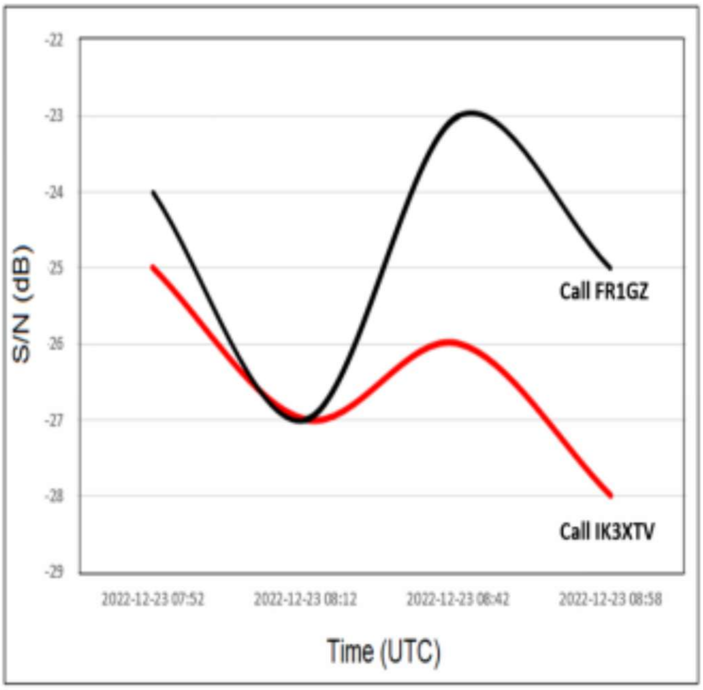


No correspondence between the two curves

The ionospheric conditions seem repeatable even along a transequatorial ionospheric path of over 8000 kilometers. The two curves in the graph below show how the shape of the curves is very similar, only the absolute values change. IK3XTV and DL6NL are almost on the same geodesic line towards FR1GZ.



Reciprocity of the ionosphere

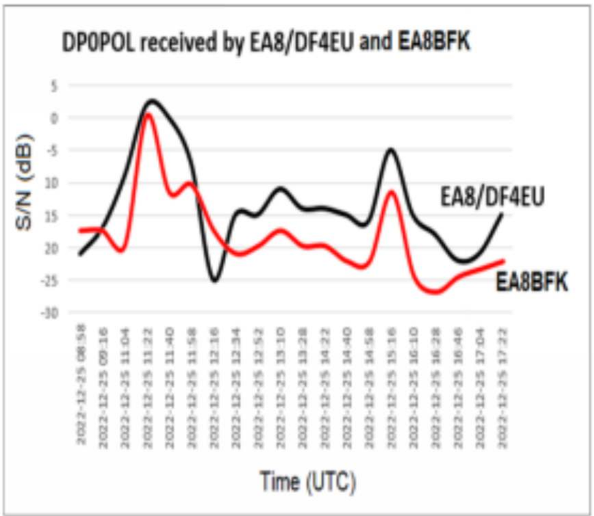


The two curves respectively show the trend of the signal transmitted by IK3XTV and received by FR1GZ in the Reunion Islands (Indian Ocean) and the signal transmitted by FR1GZ and received by IK3XTV with a 2-minute phase shift. The ionospheric path is 8635 km. Note the transmitted signal from FR1GZ (call FR1GZ) is stronger as the transmitted power is 4 times stronger than IK3XTV

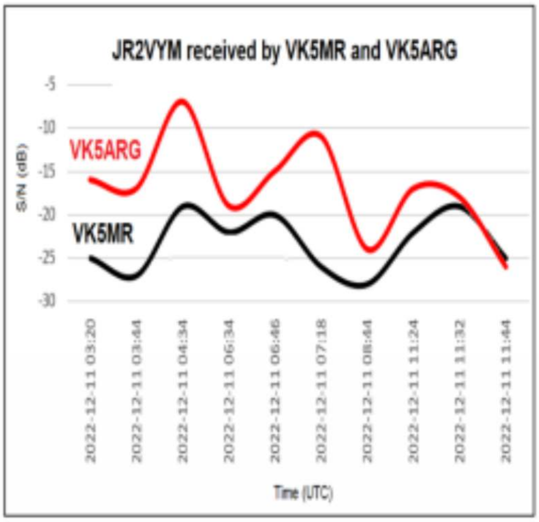
Tx power IK3XTV 0,5 W
Tx power FR1GZ 2 W

Ionospheric path 8635 Km.

Ionosphere around the world



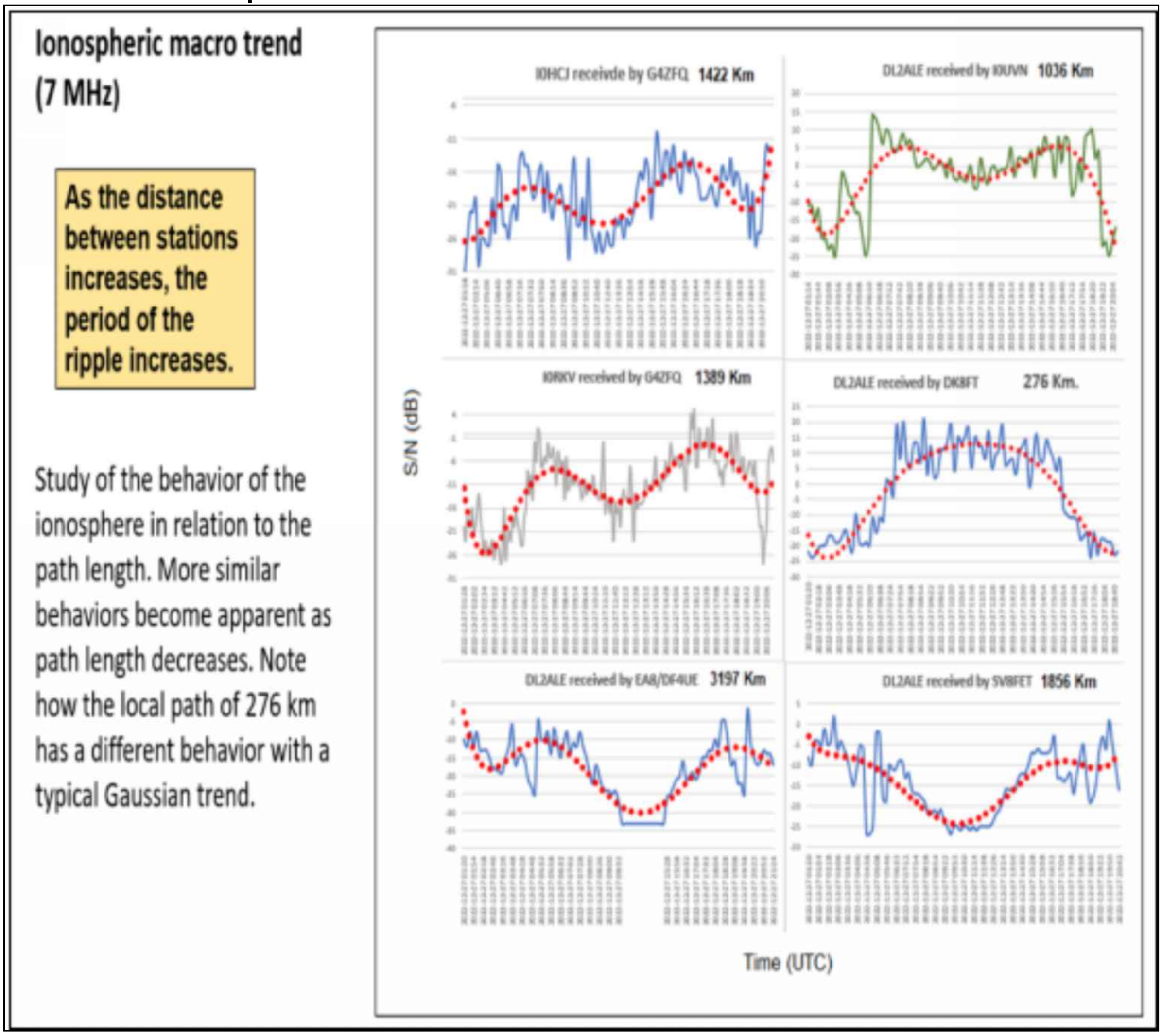
Ionospheric path 8300 Km.

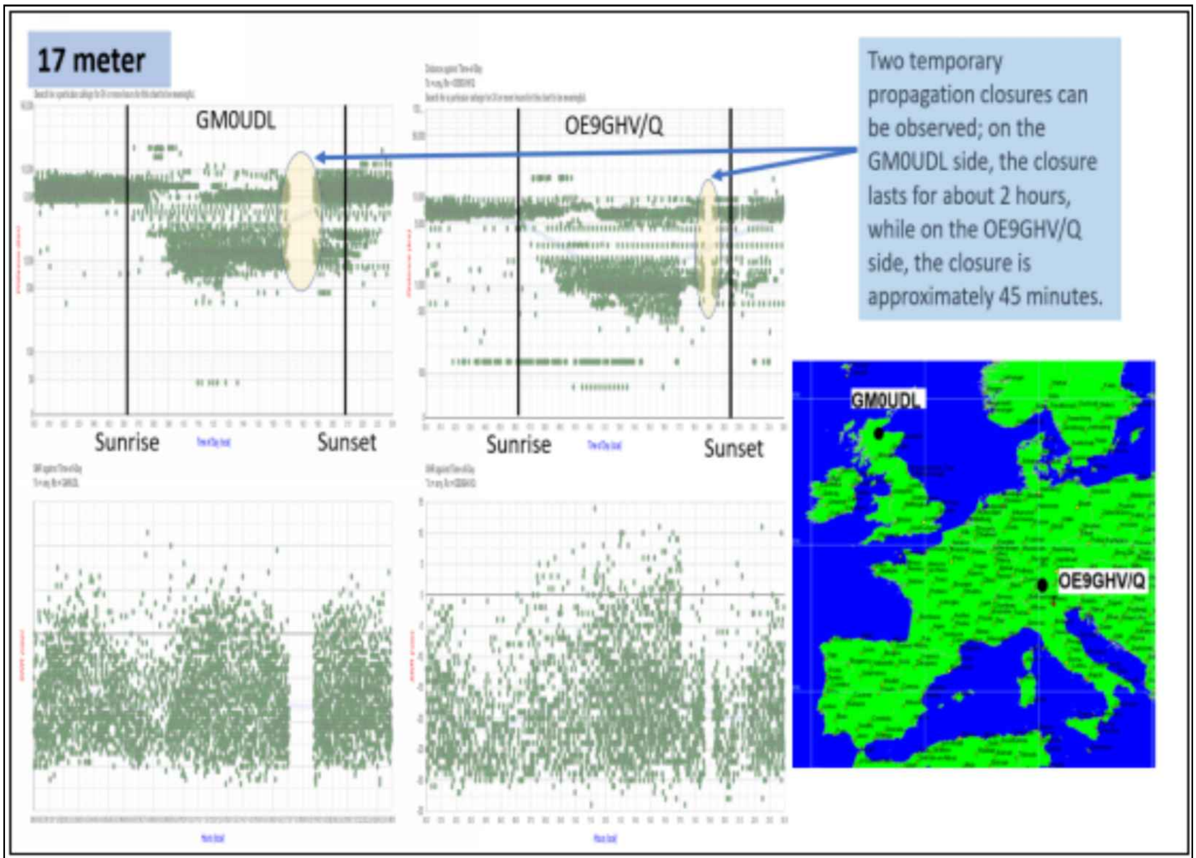


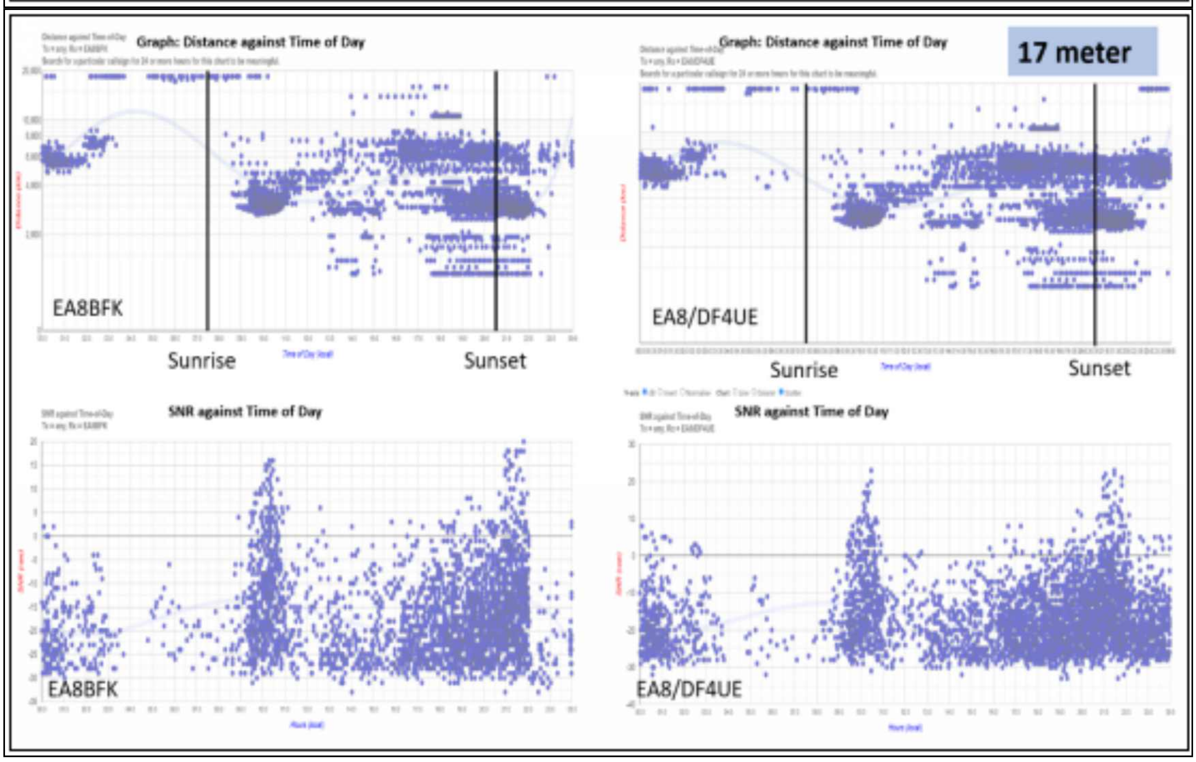
Ionospheric path 7800 Km.

I used the WSPR ROCKS program, developed by Phil VK7JJ, in order to obtain further confirmations regarding the consistent behavior of the ionosphere. Initially, I compared the receptions of the two very close stations located on the island of Fuerteventura in the Canary Islands archipelago. The results were in line with my expectations. The next 2 graphs plotting the relationship between distance and time of day are nearly overlapping over the course of 24 hours. Similarly, the graphs illustrating the Signal-to-Noise Ratio (SNR) as a function of time of day exhibit remarkable similarities. It's important to note that, although they can't be identical due to the various SNR-related variables of each station, I chose to primarily focus on the distance-related graph. In this type of graph, each point represents a received station. However, the most intriguing surprise came from the experiment repeated using two stations approximately 1300 kilometers apart. GM0UDL is located in the northern part of Scotland, while OE9GHV/Q is situated in the western part of Austria. Despite a significant difference of 10 degrees in latitude and nearly 7 degrees in longitude, even in this case, the graphs demonstrate an absolute resemblance, except for a slight discrepancy in distance. This difference is naturally attributable to the variations in geographic positioning of the two receiving stations in relation to the received

station. (I hope I haven't reinvented the wheel).




17 meter
GM0UDL
OE9GHV/Q
Two temporary propagation closures can be observed; on the GM0UDL side, the closure lasts for about 2 hours, while on the OE9GHV/Q side, the closure is approximately 45 minutes.
Sunrise
Sunset
Sunrise
Sunset
GM0UDL
OE9GHV/Q


Graph: Distance against Time of Day
Graph: Distance against Time of Day
17 meter
EA8BFK
EA8/DF4UE
Sunrise
Sunset
Sunrise
Sunset
SNR against Time of Day
SNR against Time of Day
EA8BFK
EA8/DF4UE

Conclusions

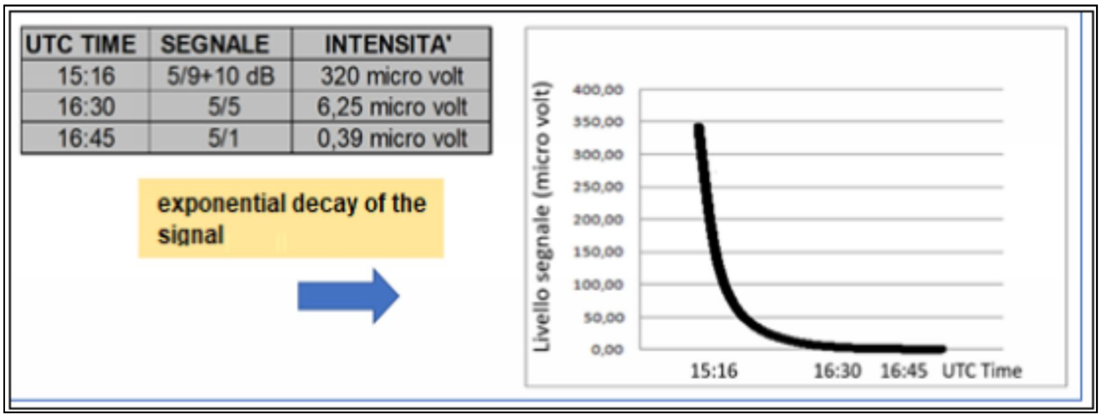
- The signal strength in absolute value varies, but signal trend is the same.
- It doesn't depend on the frequency. I have experimented on both 10 and 40 meters.
- The closer the path is, the more similar the trend is. For very close ionospheric paths the reception curves are almost perfectly superimposable.
- As you move away from the same path, the inhomogeneities increase.
- Some differences between the curves are due to a slight lag of a few minutes between one station and another
- Everything leads me to think that the conditions are reversible (fading on one side is the same as on the other side of the path).

In practice I want to demonstrate that on the same path, (connection on the same geodetic line, within a 100/200 km wide slice of the ionosphere) the ionosphere it is predictable and behaves the same for all stations. Only the absolute value of the received signal changes, because the signal level obviously depends on external factors, such as the transmitted power, the type of antenna and the location of the stations.

All maps were created with DXATLAS software by Alex Shovkoplyas,
VE3NEA.
Thanks to all the WSPR stations featured in this experiment: DL6NL, IQ8SO, G0EIG, EA8/DF4UE, EA8BFK, G8FPN, G4RVH, G0HTO, DL1FX, FR1GZ, VK5MR, VK5ARG, DO0POL, JR2VYM, DL2ALE, DK8FT,
SV8FET.

Influence of the sun on HF connections at very short distances

Taking inspiration from a local communication on the 21 MHz band with my friend Gabriella, IK3CXG, on November 22, 2002, I began to analyze the influence of the ionosphere and, therefore, the sun, even for connections over very short distances. The distance between Thiene and Piovene (where Gabriella's station is located) is noticeably short, only 7 kilometers. In a connection over such a short distance, the received signal is not as stable as one might think. For instance, the signal of IK3CXG at 15.16 UTC was 9+10 dB, but at 16.30 UTC, about 50 minutes after local sunset, it had dropped down to 5/5, and further descended to 5/1 about 15 minutes later, at 16.45 UTC. All the parameters remained constant, except for the solar radiation. The decrease in signal strength is caused by the reduction in solar radiation.
Connection between IK3CXG and IK3XTV on 21,255 MHz of 22/11/2002.

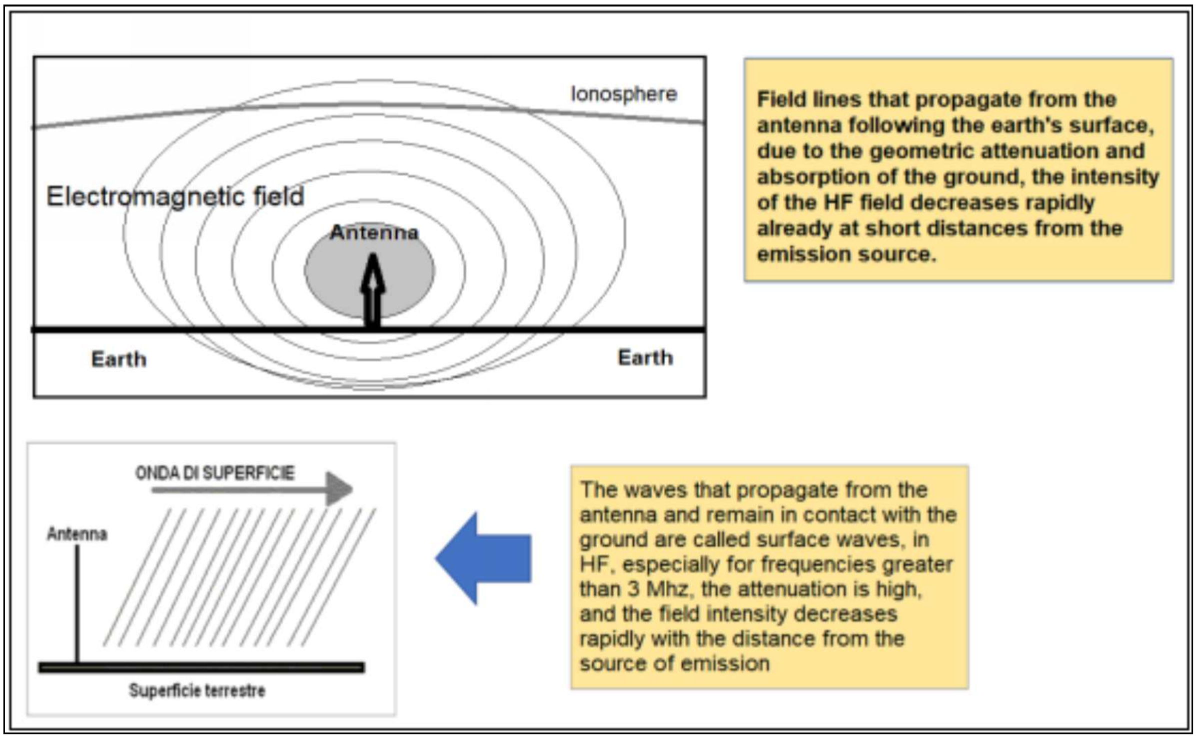


UTC TIME	SEGNALE	INTENSITA'
15:16	5/9+10 dB	320 micro volt
16:30	5/5	6,25 micro volt
16:45	5/1	0,39 micro volt

Indeed, the different irradiation of the sun on the Earth's atmosphere plays a crucial role in the dynamics of the received signal. Analyzing the behavior of the received signal, it is clear that it starts from a very high level, with a field intensity of 320 microvolts. This high intensity stays constant until the sunset of the sun, which, in Thiene, occurs at 15:37 UTC during this season. However, after sunset, the intensity of the field starts to drop gradually. By 16:30 UTC, it has already decreased to 6.25 microvolts, and it continues to descend rapidly to 0.39 microvolts just 15 minutes later, at 16:45 UTC. This rapid reduction in field intensity is a direct consequence of the diminishing solar radiation as the sun sets, leading to changes in the ionospheric conditions and so impacting the received signal.

Surface wave

Waves propagating from the antenna, while remaining in contact with the ground are known as surface waves. In the case of short waves, particularly for frequencies above 3 MHz, these surface waves experience high attenuation, causing the field intensity to rapidly decrease as the distance from the emission source increases. Vertical polarization antennas are more efficient in irradiating ground waves. The Earth's surface, from an electromagnetic perspective, is a combination of poor conductors and insulators (non-conductors), leading to absorption of the waves. The level of attenuation depends on the frequency and characteristics of the soil.



As the Earth's wave travels through the ground, it induces a voltage, and consequently, a current flows through the ground whose intensity is determined by the soil's conductivity. The increasing attenuation with frequency is due to the dispersed induced currents. Therefore, in HF (High Frequency) communication, even for short distances, there is always a dominant ionospheric component that plays a significant role in signal propagation. Conversely, the Earth's wave of ultra-long waves, with wavelengths of a few thousand meters, experiences little attenuation, allowing it to extend throughout the globe. The losses due to attenuation in the propagation of a terrestrial wave remain constant at any time of day, time of the year, and under all weather conditions, making the distance it can reach very consistent over time. Terrestrial waves can only be generated using vertically polarized antennas, and therefore, the receiving antennas must also be vertically polarized to achieve optimum results. This is different from space wave propagation, which is possible with any polarization. For quasi-optical connections, the required emission power is extremely low. For CW (Continuous Wave) and voice connections between stations on the Earth's surface, a few watts of transmission power with a

simple dipole antenna are sufficient to set up a connection with a medium-quality receiver, even if the distance between the two radio horizons is considerable. However, there is a crucial condition to achieve this level of efficiency: the corresponding antennas must be positioned at least 3 wavelengths or more above the ground and be vertically polarized. For example, for 15 meters antennas, an ideal height would be at least 45 meters above the ground. If the height is reduced to one wavelength, ten times more power would be needed. The reason for this phenomenon lies in the irradiation angle of the antenna, which becomes steeper as the relative height of the antenna decreases. As a result, the antenna tends to "look beyond" the reception area. As for the requirement for vertical polarization, the Earth behaves like a discrete conductor, especially at low frequencies. One of the laws of electromagnetism requires that the electric field lines touching the surface of a conductor do so perpendicular to it. Therefore, if the polarization is horizontal, the field lines would be parallel to the conductor (the ground), resulting in a short-circuiting effect with the ground. Hence, vertical polarization is necessary to avoid this issue.

The space waves

The space wave is that part of the wave front radiated by the antenna that is reflected by the ionosphere.

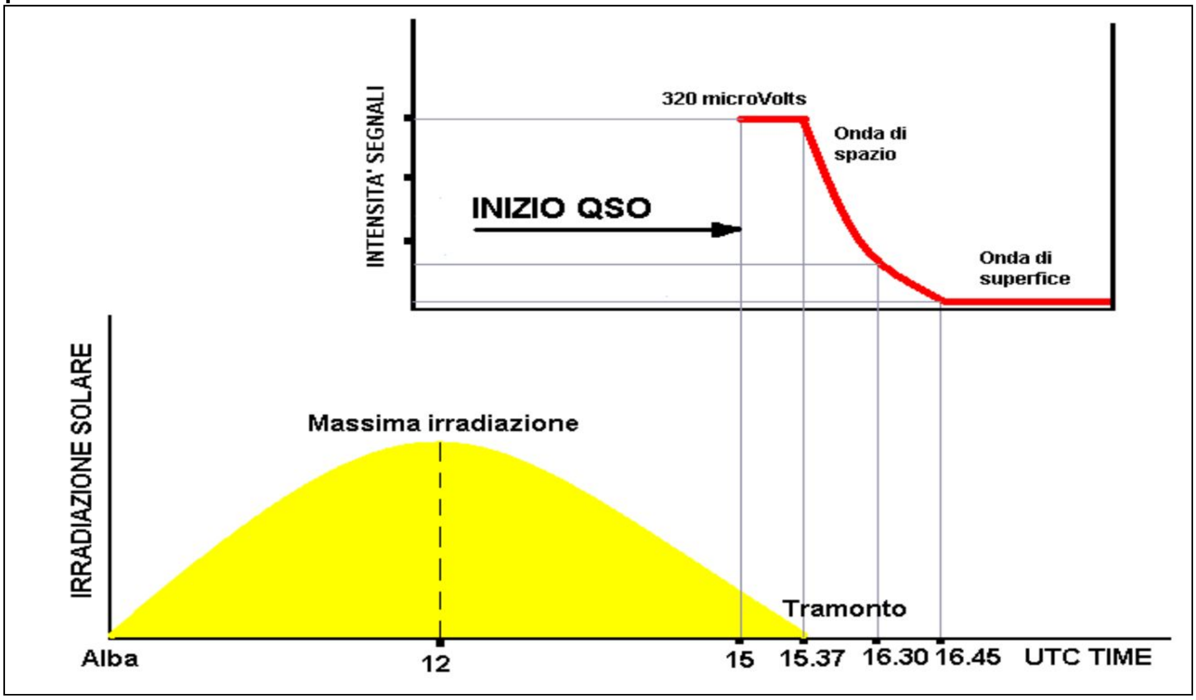
The reflective layers of the ionosphere do not have constant characteristics. They vary in height, degree of ionization and intensity because of solar radiation, not only with the alternation of day and night and seasons, but also depending on the one-decade cycle of sunspots.

This multitude of influential factors explains how the propagation of the space wave is not constant.

The variability of spatial wave propagation is even more accentuated by the fact that it also depends on the angle of incidence of the reflected spatial wave, its frequency, and the degree of ionization (gradient) of the reflecting layer.

Influence of the ionosphere

The wave front emitted by the antenna is very wide and, especially in my case horizontal polarization (rotary dipole) The emission conditions of the ground wave are the worst possible.



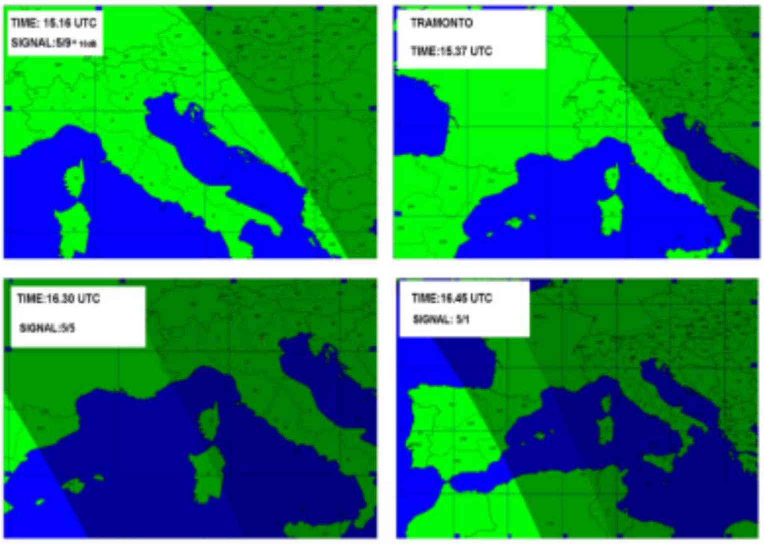
As already mentioned, the very wide and horizontally polarized wave front propagates in the surrounding space (which is the curved ionosphere). The main fringe of the wave front enters the Earth's ionosphere and for diffuse reflections is progressively curved even thousands of kilometers away. For an understanding of propagation, we must imagine the signal radio not as a distinct beam (a straight line) but as a sphere of energy that envelops the surrounding space including the ionosphere at the top.

Fig. Trend of signal intensity in relation with solar irradiation. It must be considered that the signal is proportional to the sun's radiation but due to the influence on propagation there is a hysteresis due to the non-immediate deionization of the ionosphere after sunset.

A part of the energy of this sphere, when in the middle finds the ideal conditions for reflection (in the ionized ionosphere), is curved to the ground and then picked up by the receiver. There is a widespread reflection favored by the ionospheric layers above, even if the distance between the two stations is short. Another important aspect to consider is the angle of irradiation, in my case irradiating with a rotary dipole, the angle is high and therefore being the vertical component of the wave front improves the reflection by the Ionosphere above, spreading the signal all around. Vice versa, low irradiation angles, allow a lower wave front to be irradiated near the horizon with best conditions for long distance communications, in other words there is a lower dispersion of energy upwards.

Some considerations

From the analysis of the signal dynamics related to the sun's irradiation (as shown in the maps on the next page), the field intensity reaches its maximum when the sun is still high over the horizon, causing strong ionization of the ionospheric layers. Additionally, the field intensity remains constant until the sun sets (at 15:37 UTC), as there is a gradual decrease in ionization after sunset, but residual ionization persists. However, about 50 minutes after sunset, the field intensity level drops significantly (reaching 6.25 microvolts), and 15 minutes later, it falls even further to 0.39 microvolts. At this point, the ionization may no longer be sufficient to support signal propagation, and the electric field's value is determined primarily by the surface wave. It should be noted that the reflective ionospheric layers at higher altitudes "see" the sun for a longer duration compared to the ground level. This phenomenon, known as hysteresis, leads to a gradual deionization of the layers after sunset. However, on the 21 MHz frequency range (for example), this deionization process is rapid. An interesting confirmation of these observations comes from connecting to the station IN3LQB in Rovereto on 15 and 17 meter during daylight hours, with a signal strength like that of Gabriella (S9+5 dB). Although Rovereto is located about 50 kilometers away from Thiene, it is in the valley floor behind the Pasubio mountains, at an altitude of about 2300 meters. Due to the high shadow wall of the mountain, surface wave propagation in this case is almost impossible. Therefore, it is evident that the propagation mechanism in play is the same as described earlier, where the influence of the ionosphere and the sun's ionization (especially for higher frequencies in the HF spectrum) is crucial even for very short-distance HF communications, and the space wave becomes the dominant component. The variations in field intensity observed in these scenarios were extremely high, exceeding 300 microvolts.



The maps with the Grey line, chronologically show the evolution of the sun and the evolution of the received signal. The absorption of the lower layers of the ionosphere (D region) at 21 MHz is negligible, so the differences in intensity are due to the greater or lesser ionization of the reflective layers of the ionosphere, activated by the solar flux. For completeness of information, the solar indices of 22-12-2002 are as follows:
A index=25
Sunspot number=125
Solar flux=150

Map created using the DX Atlas software, www.dxatlas.com.

Fading on local communications

Another interesting contribution to understanding the behavior of shortwaves on local connections is what I found during a connection with my friend Loris, IK3PCZ. I would therefore like to analyze this strange phenomenon saw on the frequency of 18Mhz: During the QSO in the morning of March 16, 2003, with IK3PCZ. Loris radiated with a vertical antenna placed on the roof of his home while I operated with a simple Yagi 2 elements, for the 17 meters. The strangeness of the phenomenon refers to the fact that the signal emitted by Loris with its vertical was subject to a deep fading, (from S1 to S9) in terms of field intensity the variation is extremely high, varying from 0.2 to 50 microvolts. We tried with a different antenna (cubical quad 2 elements) and the signal was stable. The emission power (always kept constant) for both was ten Watts, therefore very low. Ci must be an interaction (and anomalous) with electromagnetic emission capable of making the field intensity unstable and related to the difference in polarization, as discussed above. IK3PCZ station is in Marano Vicentino, at approximately 4 kilometers from my home in Thiene.

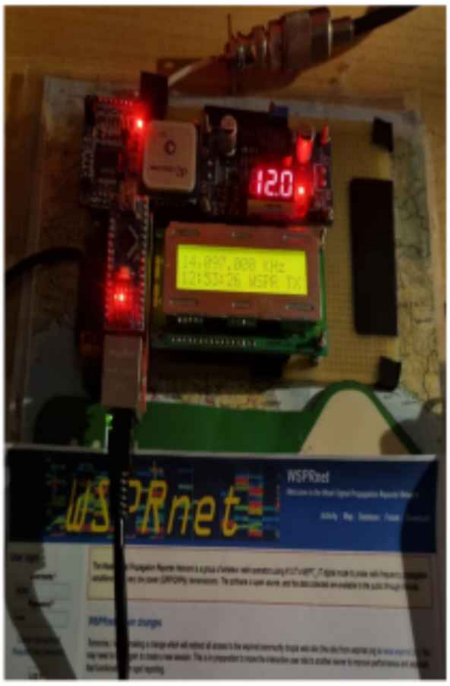
Fading
Fading or fading is the random fluctuation of the received signal.
The fading is due to the interference between the waves that arrive at the receiver following different paths. These are rapid variations that affect the signal in both amplitude and frequency.
Variable attenuation of the signal due to temporal variations in the characteristics of the medium where the propagation of waves takes place. This attenuation is slow over time.

Signal fading considerations
The rapid fading of IK3PCZ signals could be attributed to the fact that the electromagnetic waves received by the antenna may have followed different propagation paths. Since Loris transmitted with a vertical antenna, the dominant component of the received signal was the surface wave. Although the attenuation at 18 MHz is high, the short path length between the stations may not introduce excessive attenuation. However, in addition to the surface wave, there is also a space wave (in this case, secondary) that is scattered by the ionosphere, following a different path. Normally, the dominant energy arrives via one path, and in our case, the surface component is dominant. However, the contributions from other paths can cause fading, either short or long in duration, depending on the characteristics of the different propagation modes. In our case, the fading is rapid, likely because random effects accumulate, leading to sudden variations in the signal strength. The evidence supporting this hypothesis is that when IK3PCZ transmitted with a horizontal polarization antenna, the surface wave became almost irrelevant, and the signal was not affected by fluctuations. This confirms that the fading observed with the vertical polarization antenna was due to the combination of different propagation paths and their random effects.

Experiments of ground wave transmissions with beacon WSPR (IK3XTV-IZ3QAQ) We are in January 2022 and more than 20 years have passed since these rudimentary experiments, made in SSB and without specific instrumentation. Technologically speaking, many more years seem to have passed. It is called historical acceleration Twenty years ago, we were sailing “on sight”, like the drivers of the Mille Miglia race in the 40s / 50s, who drove instinctively with manual instrumentation and sometimes even without indicator tools. The advent of new amateur radio technologies, such as SDR radios and digital modes, especially those protocols designed specifically for weak signals and for the study of propagation, such as WSPR, have forever changed radiantism and have allowed a more scientific and instrumental approach that allows to carry out more reliable experiments. I use the maybe, because there are always a whole series of unknowns and uncertainties, linked to the random nature of electromagnetic waves. In physics, electromagnetic radiation is the propagation in space of the energy of the electromagnetic field. According to classical electrodynamics, it consists of electromagnetic waves, consisting of synchronized oscillations of electric and magnetic fields that in a vacuum, travel at the speed of light. Now try to think intimately about the concept of electric field or magnetic field and try to describe it or understand how this can be done. I tried. I haven't succeeded yet. The experiment described below is inspired by these considerations. For such a study, you cannot use the power of an atomic power plant, you cannot even use the classic 100 watts of an amateur radio transceiver. You need a weak signal, a signal that behaves like a leaf carried by the wind. WSPR “whisper,” means "Weak Signal Propagation Reporter". The software is designed to test radio propagation path using low-power transmissions such as "beacons". A WSPR signal transmits the call sign, the locator, and the TX power, using a compressed data format and a powerful error correction code, transmitted by 4-FSK narrowband modulation (4 tones). The protocol is

efficient up to Signal-to-Noise ratios of -28 dB in 2500 Hz. The receiving stations, if connected to the Internet, can automatically send the receiving reports to a centralized database. The WSPRNET website supplies a simple user interface for querying the database, consulting maps, and other functions. I used the transmitter beacon WSPR engineered and made by my friend Daniele De Marchi, IU3AGC. Daniele's beacon can transmit over the entire HF spectrum with an output power of 0.001 watts. I asked for the collaboration of another amateur radio friend, Marco Faccin, IZ3QAQ. The idea was to study this "field" with a transmission at a short distance and with a very low signal, a “limit” signal. Why a "limit" signal and not a signal with power? Simple, because it would be like wanting to measure the variations of the sea breeze with an oil tanker. A weak power signal is almost "transparent" and allows me to "see what is behind it". The distance of IZ3QAQ from my station is about 850 meters. So, I configured the beacon in transmission on the frequency of 14,097100 MHz (20 meters) in WSPR mode in H24 transmission, that is, continuous 24 hours a day with sequences of 2 minutes. Marco tuned his receiver connected to an Hexbeam 6-band antenna and through the computer and the WSJTX program, automatically recorded the data for a week. The WSJTX software, among other wonders, must record and upload all the spots on a cluster on the web called WSPRNET, from which you can download listening data in real time, create reports and analyze the data. The most effective method I know to analyze data is always the same, that is, the one that an old mathematics professor of mine taught me: *“If you want to analyze data you have to put this data on a graph, because an image speaks much better than many words".* What you see reported here, is the graphic form of all this reception work, which would like to have the claim to "reveal" something more about the famous field and the HF propagation by ground wave. Observe from the graphs how the field of a signal can vary in 20 meters, over 850 meters. Moreover, according to quantum physics, the

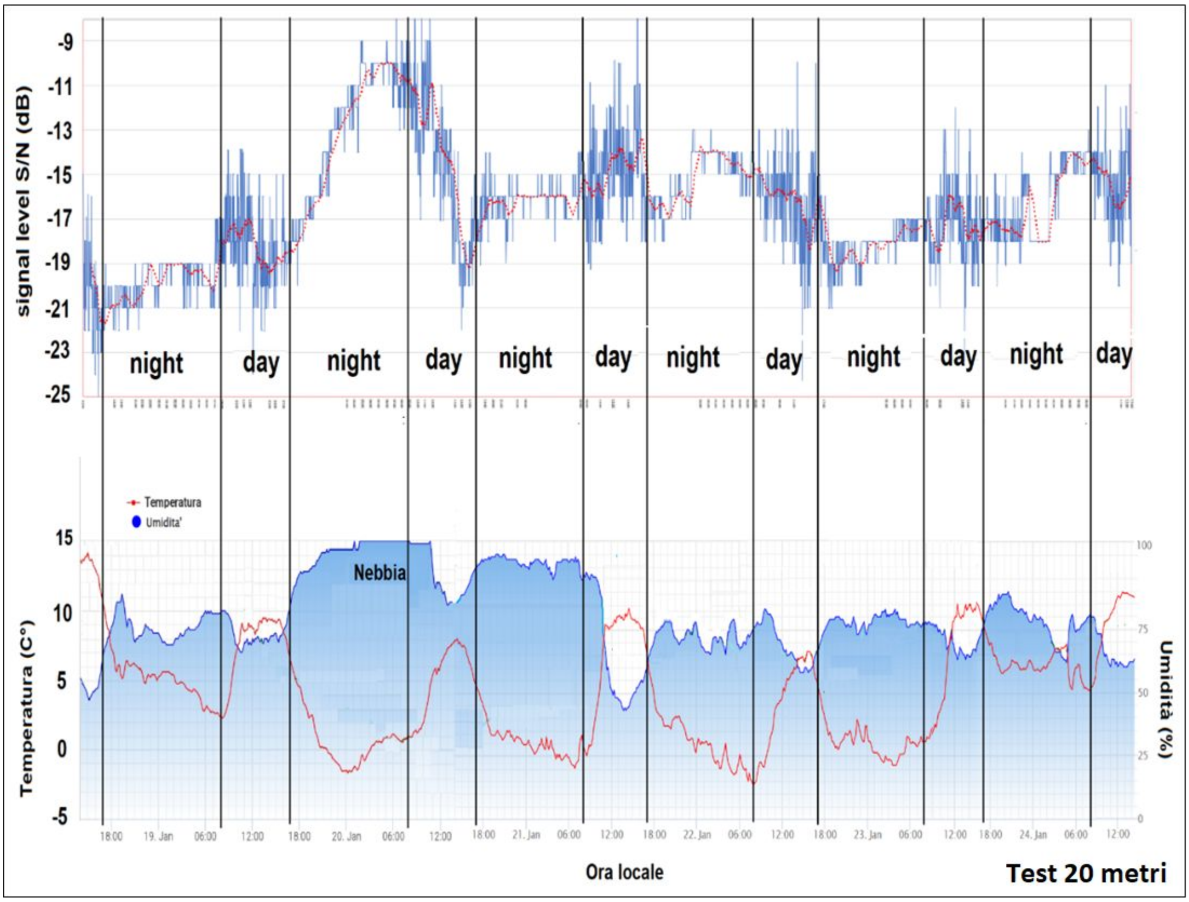
entire world around us is composed of waves. Waves that behave like particles, particles that cross barriers like ghosts or that communicate with each other. Wave or particle? this is the great strangeness because all particles, and consequently everything that surrounds us, have a double nature: In some cases, they behave like corpuscles, in others like waves. A strange world, isn't it? But the most curious phenomenon is entanglement ("weaving"). Imagine taking two photons in an "overlap of states", we can think of them as coins spinning endlessly, showing both faces (head or cross) and subjecting them to entanglement, and then taking them to opposite sides of the universe. According to quantum mechanics, if we make a measurement on one of the two, and obtain for example head, the other coin, instantly, also ceases to be in an indeterminate state: if we measure it (after a second or after a century) we are sure that the result will be head. The two particles are as if in telepathic contact. This seems absurd, in fact it is what in quantum mechanics it is called, entanglement



The WSPR beacon

The aim of this project is to create a Hamradio WSPR Beacon as small and economical as possible, but with advanced features such as an ethernet connection. The hardware chosen for this project is an Arduino Nano (or a clone), an ENC28J60 ethernet shield and an AD9851 DDS. A GPS receiver and a 16x2 character LCD display has also been added. The system must synchronize the clock for the WSPR transmission. If GPS is not installed (or not receiving) the system will use the configured NTP time server. The distinguishing feature of this system is that it can be reached via ethernet to monitor the status and configure the system. The output power is 0.001 watts, programmable on all amateur bands. The beacon was designed and built by Daniele De Marchi, IU3AGC.

that can be translated as correlation. *(Meteo data and temperature and Humidity graphs by avmeteo.it).*

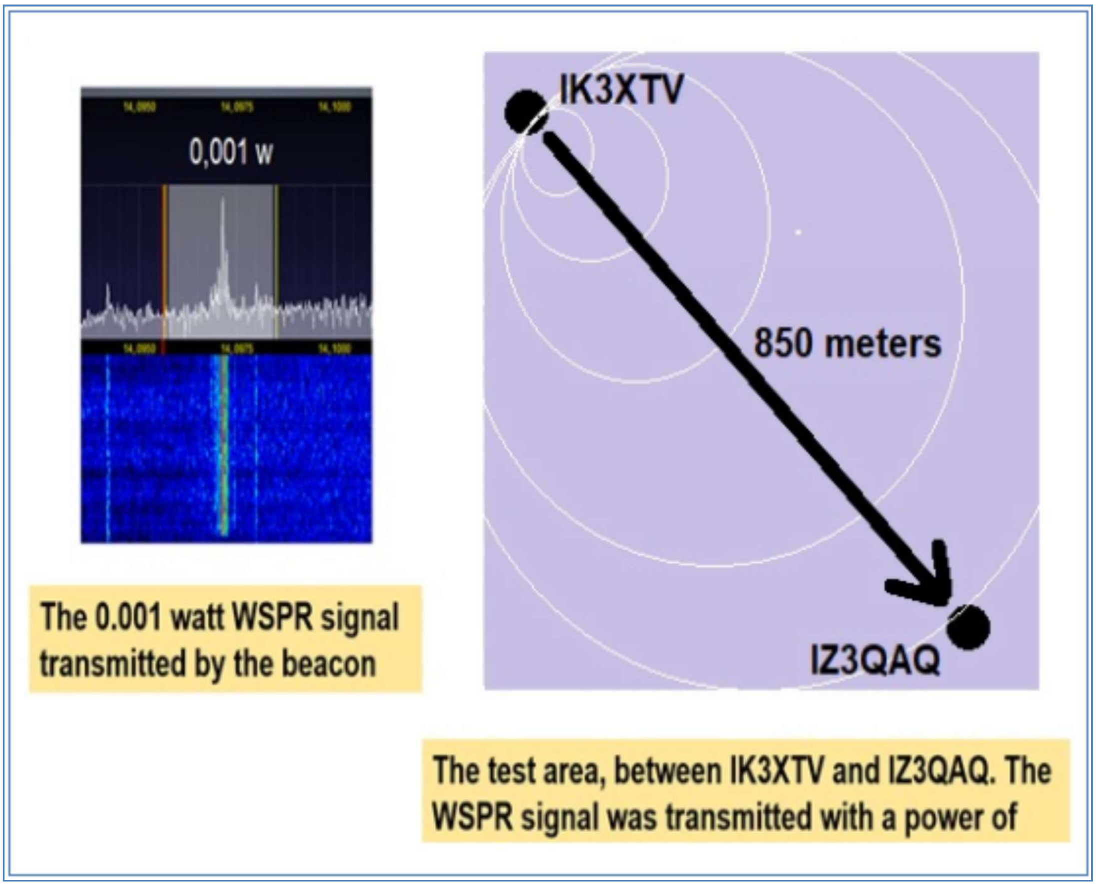


The signal in dB of WSJTX is an S/N, this means that it is not an absolute value, but a ratio. A ratio of signal to noise, so it is obvious that the value in dB increases if the noise level decreases. The first consideration that comes to my mind is to observe how the field varies over such a short propagation distance, in this case less than a kilometer. Small variations in atmospheric parameters introduce important variations on the electromagnetic field. Paradoxically, a field that moves through the ionosphere should undergo fewer interactions. We are in the presence of what in physics is defined as a complex system, that is, a dynamic system with multi components or composed of different subsystems that typically interact with each other. Notice the signal spike in conjunction with a foggy night. The test was conducted in the absence of rain, in conditions of high atmospheric pressure, in the middle of winter from 18 to 24 January 2022. (Vertical lines in bold mark the local sunrise and sunset. Credits: weather graphics provided and granted by the website www.avmeteo.it.

Chart analysis in 20 meters

From a first analysis of the graph, we can see 4 factors that seem to act on the electromagnetic field emitted by the antenna of IK3XTV and received by IZ3QAQ.

1-Day/night variation: Greater daytime fluctuations are noted, while during the night hours the field is more stable.
2- The humidity and temperature curves tend to be in phase opposition.
3- The increase in the % of humidity has an important impact because it affects the field, increasing the strength of the signal (S/N) as happens for example during the night with the fog, highlighted in the graph.
4- The signal received by IZ3QAQ seems to be the result of the relationship between humidity and air temperature and UV radiation from the sun, but for UV radiation we have no instrumental data.
5- There is another unknown related to the contribution of solar irradiation to the ground. Not having data available, I am not able to establish if there is a connection with the tendency that the signal must increase during daylight hours. Chart analysis in 20 meters.



Test in 60 meters

After the test in 20 meters, I focused my attention to a lower frequency, and I chose the new band of 60 meters. I report the result obtained on the 60 meter band, for a couple of days of registration. The result is completely different, where we can see a sinusoidal trend. The antenna used is a V-shaped dipole.

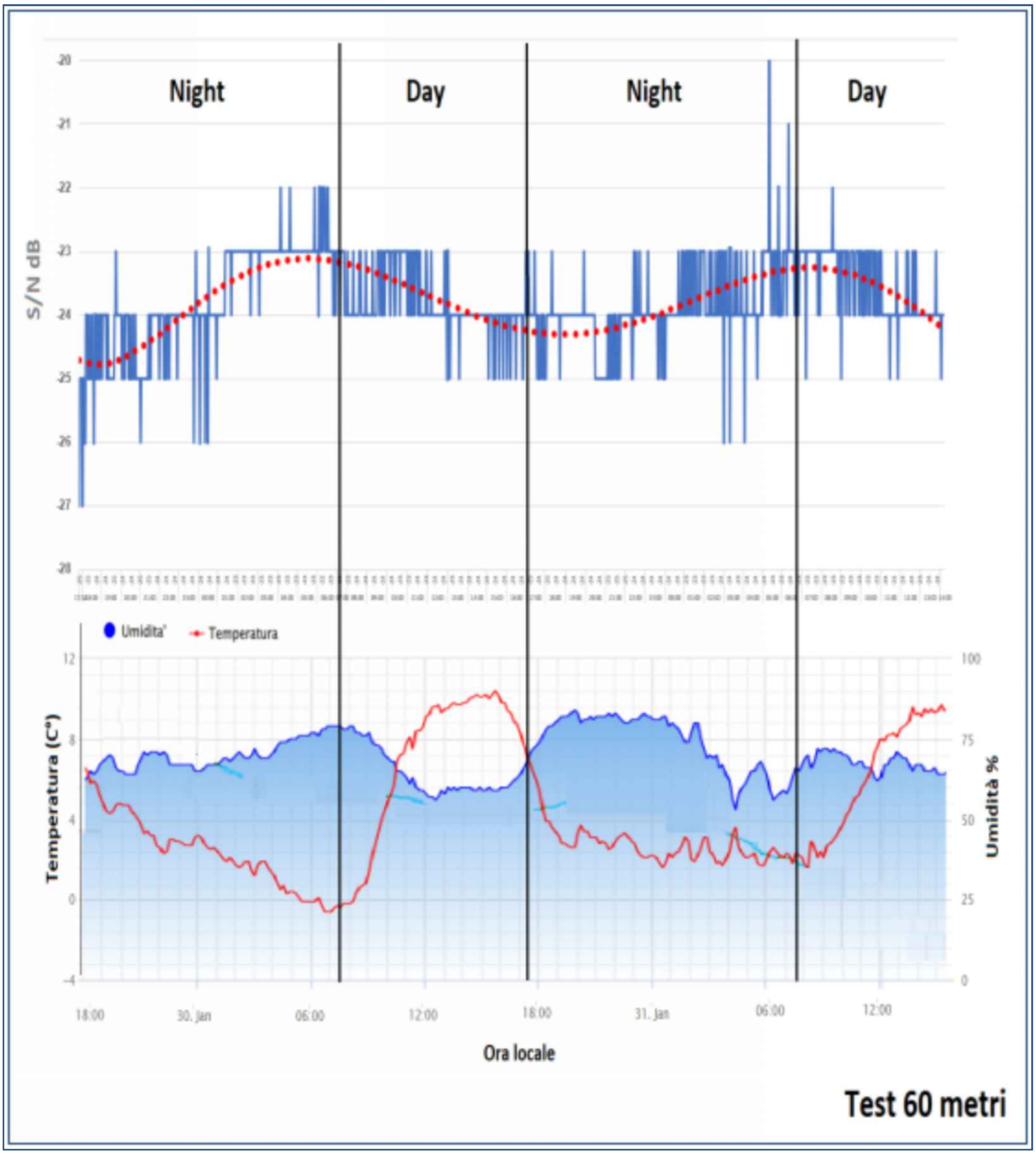


Fig. Test on 60 meters with V-dipole reception. The maximum variation range is 7 dB.

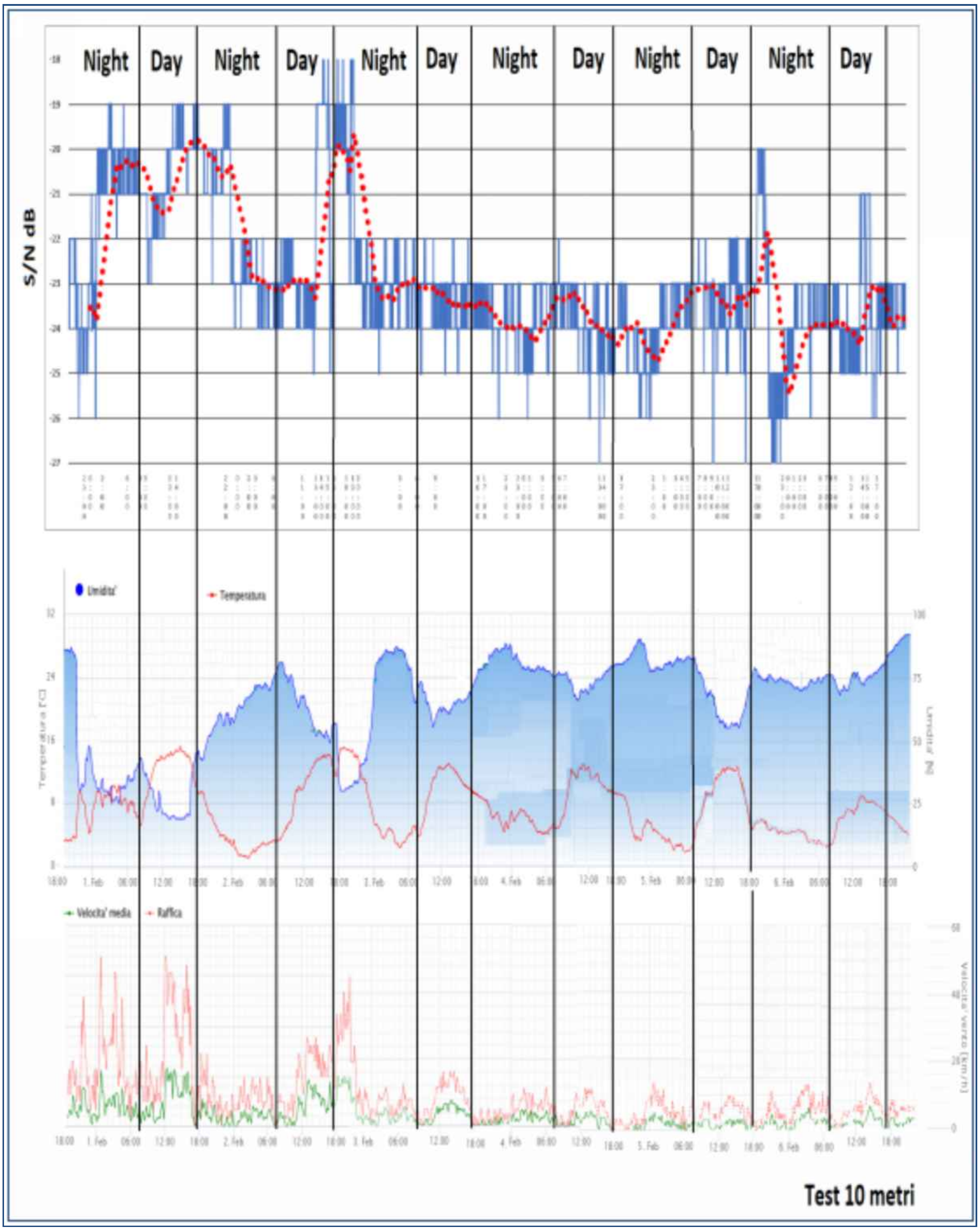


Fig. Test in 10 meters with V-dipole antenna reception. The maximum variation is 10 dB.

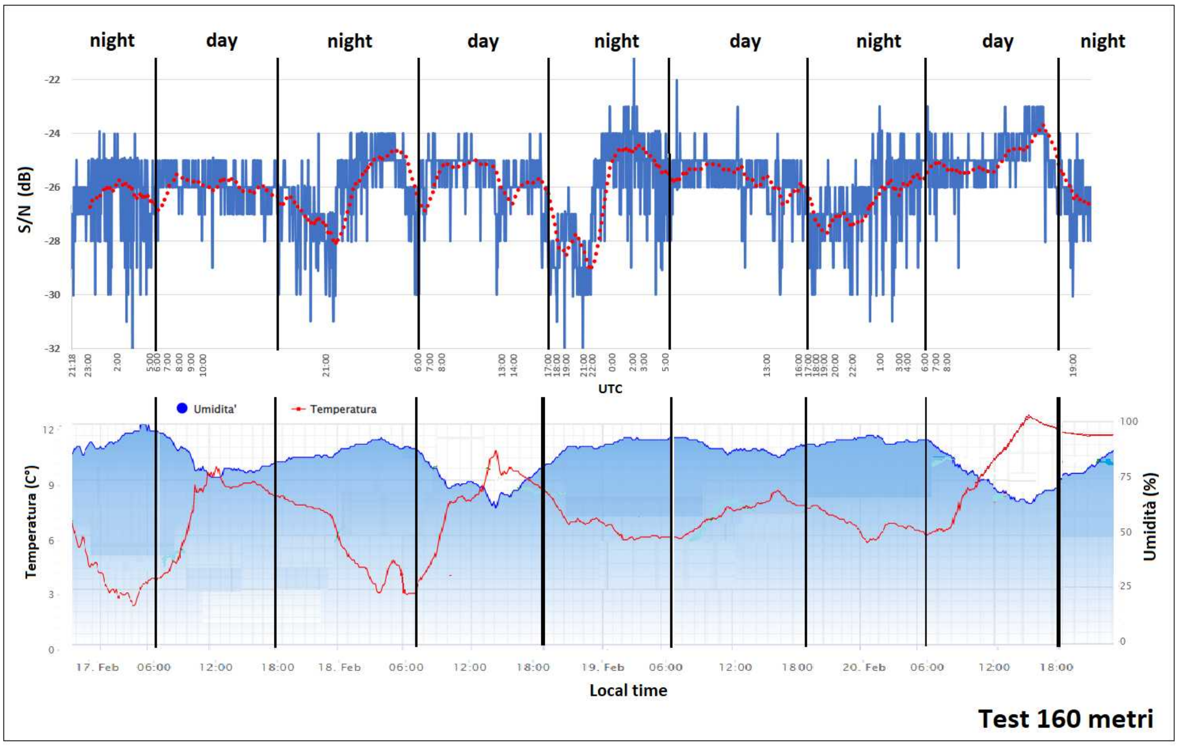
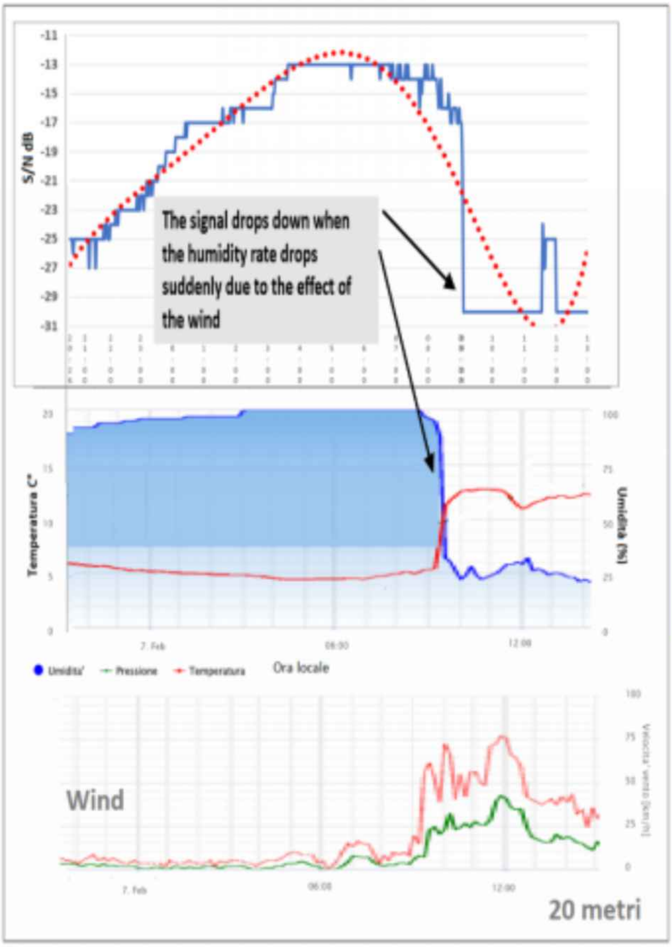


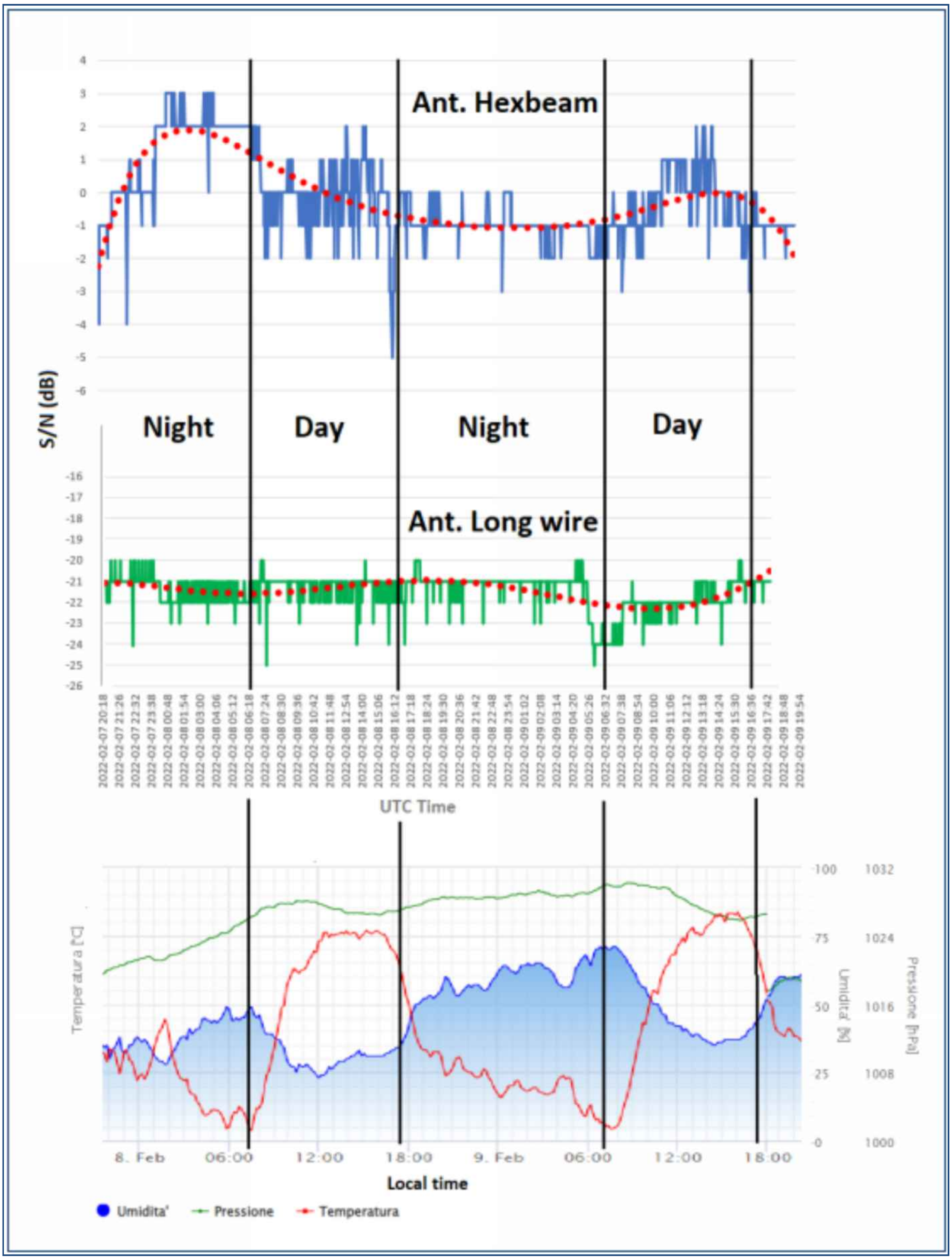
Fig. On the 160 meters, I expected a very stable signal, instead the result is what you see in the graph. The test was done with antenna Windom for transmission and vertical antenna for reception. The signal trend has a certain daytime stability and marked night instability. Consider that noise on the 160 meters is important. We are measuring not an absolute value, but a signal-to-noise ratio, S/N. Night instability may be due to greater fluctuations in night noise. At the bottom of the graph, I reported the weather parameters, such as temperature and humidity %. It is difficult to find the connection between the weather parameters and the signal trend. There are several factors that contribute at the same time: temperature, humidity, noise level and solar irradiation. The temperature- humidity scissor plays a significant role here as well.

The role of humidity% of the air



The WSPR experiments clearly show that air humidity plays a decisive role in the propagation of the electromagnetic field. As can be seen from this experiment in 20 meters. The S/N level in dB of the signal began to progressively increase with the increasing in air humidity. This is due to a violent Föhn wind perturbation that hit northern Italy, the humidity dropped abruptly and consequently the signal also dropped down rapidly, with a step effect.

The presence of moisture, both in the form of liquid and steam (water, in fact, has a strongly dipolar structure, thus producing a significant increase in the dielectric constant). The level of humidity of the air also affects the dielectric properties and therefore of its physical characteristics. The latter are variable as a function of depth and horizontal development, but in short waves we can assume the soil locally uniform in horizontal directions, and the depth of penetration is small and such that we can consider only the surface layers of the soil. The physical characteristics that influence the dielectric constant are the water content, which is the most important variable. The other variable is temperature. The difficulty in understanding how these two parameters affect each other is that they have their own inertia and this makes the system difficult to frame.



Ant. Hexbeam
S/N (dB)
Night
Day
Night
Day
Ant. Long wire
UTC Time
Temperatura [°C]
Umidita' [%]
Pressione [hPa]
8. Feb
06:00
12:00
18:00
9. Feb
06:00
12:00
18:00
Local time
Umidita'
Pressione
Temperatura

Fig. Reception experiment on the 20-meter band, with two different antennas: Hexbeam 6 elements and long wire. The results are different. The trend curves are different. I suspect that switching from an antenna like the Hexbeam to a long wire, may introduce depolarization effects. The wave has a polarization of its own. If it affects elements of dissymmetric shape, a partial transfer of power on the orthogonal polarization may take place with consequent variation in the signal strength. In the case of the Hexbeam antenna, the signal has a marked instability during the day, while it has slight variation when received with a long wire antenna.

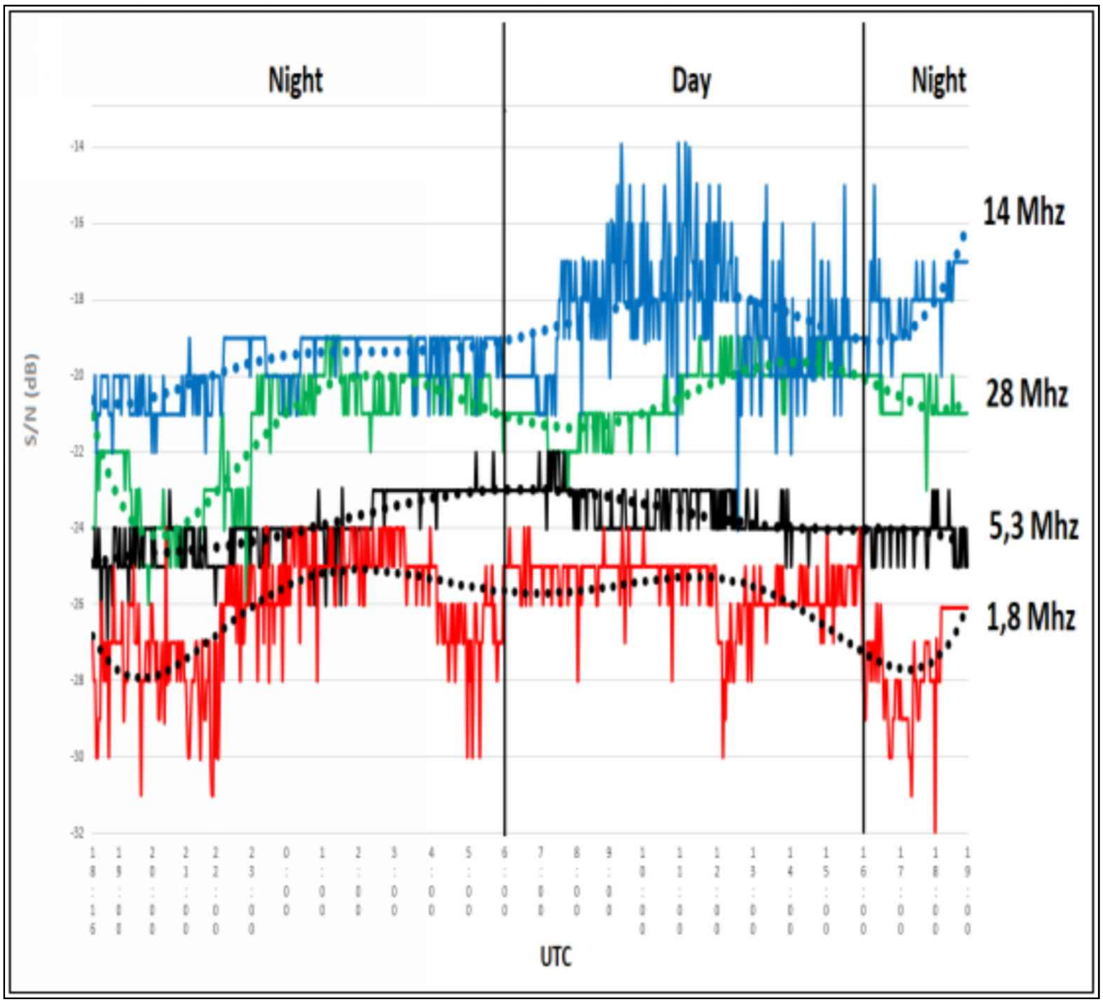


Fig. Comparison of the reception curves between the four frequencies tested (1.8 - 5.3 - 14 - 28 MHz). It makes no sense to look at the S/N value of the signal, but at the trend of relative intensity and the trend of the signal over time. The 20 meters show the greatest instability together with the 160. The band with the most stable behavior is 60 meters, while the behavior of 10 meters is a middle way between 20 and 160 meters. The 20 meters show greater daytime instability, while the 160 meters behave in the opposite way and show a more marked night instability. This could be due to a difference in noise behavior on the two bands.

Conclusion

When you think you have all the answers, reality changes all the questions. However, as difficult as it is for me to draw conclusions from such a complex system, I try to make a minimum of summary.

The clearest points are these:

-Humidity plays a significant role and seems to be the key parameter that determines the intensity of the signal, especially on ranges greater than 60 meters,

-The long wire antenna behaves differently than the others.

- During the day, the signal has greater fluctuations.

-The range of 20 meters has fluctuations greater than 10 meters and is more unstable.

-The 60 meters are very stable and are very little affected by the day/night variations.

Doubts:

-It is not clear how temperature and humidity interact with each other.

-It is not clear why the 20 meters are more unstable than the 10 meters.

But in the end, we will never have all the answers, because the right answer we will never know and right here, in this mystery, lies all the charm of the propagation of radio waves.

(All of these experiments were done between January and February 2022.)

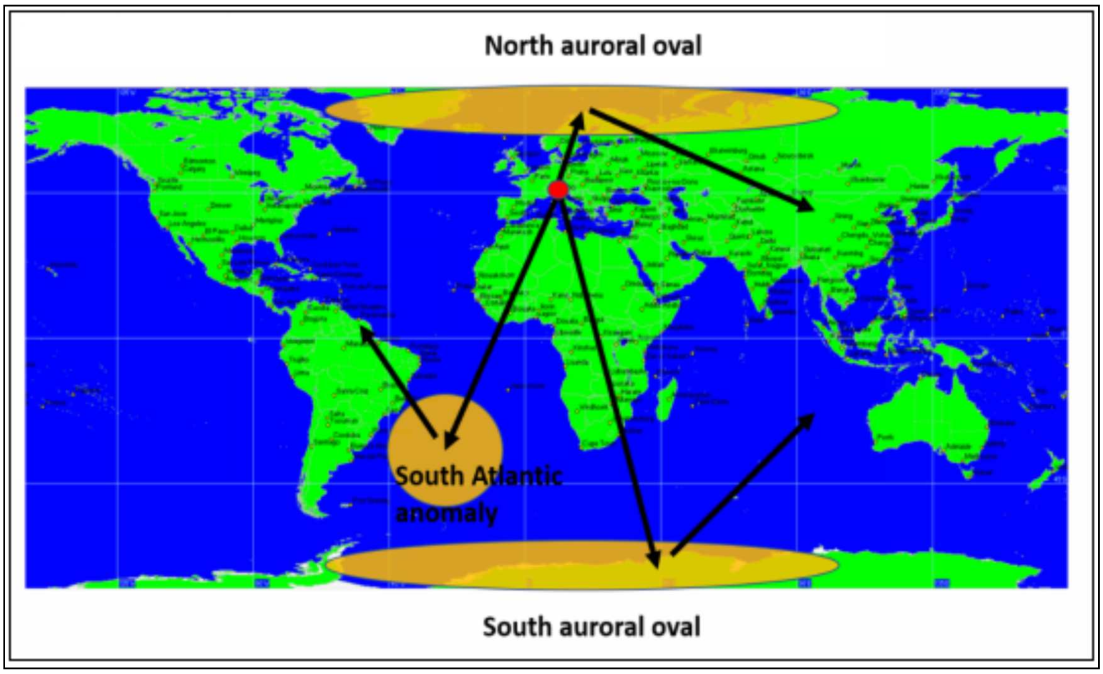
Note: the weather data and the graphs have been provided and granted by the website www.avmeteo.it

Azimuth deviations

Most often it happens to listen better to the correspondent with the antenna in another direction than its real geographical location. The observations are related to the high frequencies of HF, perhaps because the use of directional antennas lends itself to better observation of the phenomenon, moreover higher frequency signals are more sensitive to deviations related to the variation of the ionization gradient. These are major azimuth deviations, which I would like to go into in more detail in order to try to explain the phenomenon. From my practical experiences and discussions with other MOs, three anomalies have emerged, of which I have knowledge.

- Azimuth deviation to the North Pole
- Azimuth deviation to the South Pole
- Azimuth deviation to the South Atlantic

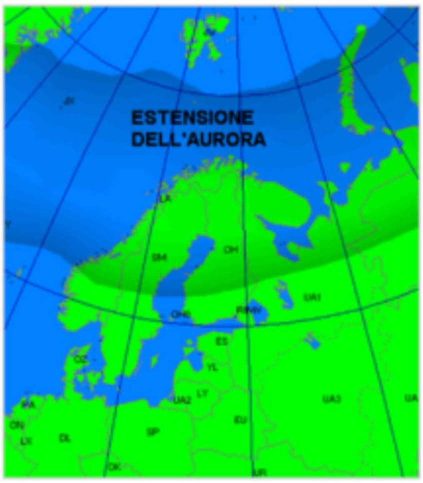
On the map below, I summarized the deviations that I know.

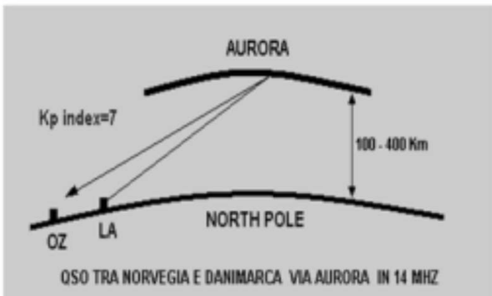


Map created using the DX Atlas software, www.dxatlas.com.

Reflection on auroral ovals

Thanks to the report of an OM friend, Tony De Longhi, IZ2ESV, who is in contact with a station operating in southern Norway, we have proof of the possibility of reflection of the signals by the Auroral curtains. This is Ketil Olsen LA2UJA with whom we have established a collaboration for the study and observation of Ionospheric propagation. His friend Ketil exploits an observatory being in Kolnes, over 60° north latitude and therefore in a privileged position for the observation of phenomena related to the Polar Ionosphere and auroras. The experience reported by the Norwegian, which with the antennas to the north, connected with a strong and stable signal, a station from Denmark that in turn radiated northwards, on the 20-meter band, (pointing the antenna directly towards Denmark the Danish station was not listenable, geographically the south of Norway and Denmark are close) shows that there is a real possibility of reflection, even for HF frequencies on the auroral courtyards. A more in-depth analysis of this interesting qso, which took place on February 1, 2003, at 22.23 UTC on the frequency of 14 MHz, showed that auroral activity was intense, also confirmed by the high geomagnetic activity with a Kp=7 index, there is in fact a close correlation between the Kp index and aurora radio.





In the image above, I reported the dynamic of the signals reflected from the auroral oval, while in the map at left, I reported the aurora extension for a Kp index =7 at 22:23 UTC of 01/02/2003. As you can see the auroral plasma reaches as far as southern Norway.

In the same way as this direct reflection, deviations or lateral reflections could occur for those signals that lap the auroral curtains, especially when, due to the high geomagnetic activity, they widen in extent and in density.

Azimuth deviation to the North Pole

In connections to the East-American Coast, (the best pointing angle is about 300°) you notice at times an improvement of the signal by pointing the antenna towards the north pole, so about 60 ° difference, it is probably a better refraction introduced by the presence of the Auroral oval, which at certain times due to the solar wind, widens to the South, the same thing happens for those signals that go in the opposite direction to Japan, especially in the morning when the extent of the aurora is greater from the illuminated side. The Auroral oval is not static but moves following the pressure of solar radiation (effects of the solar wind), therefore especially on the illuminated side, the oval southward enlargement affects the radio wave passing around there.

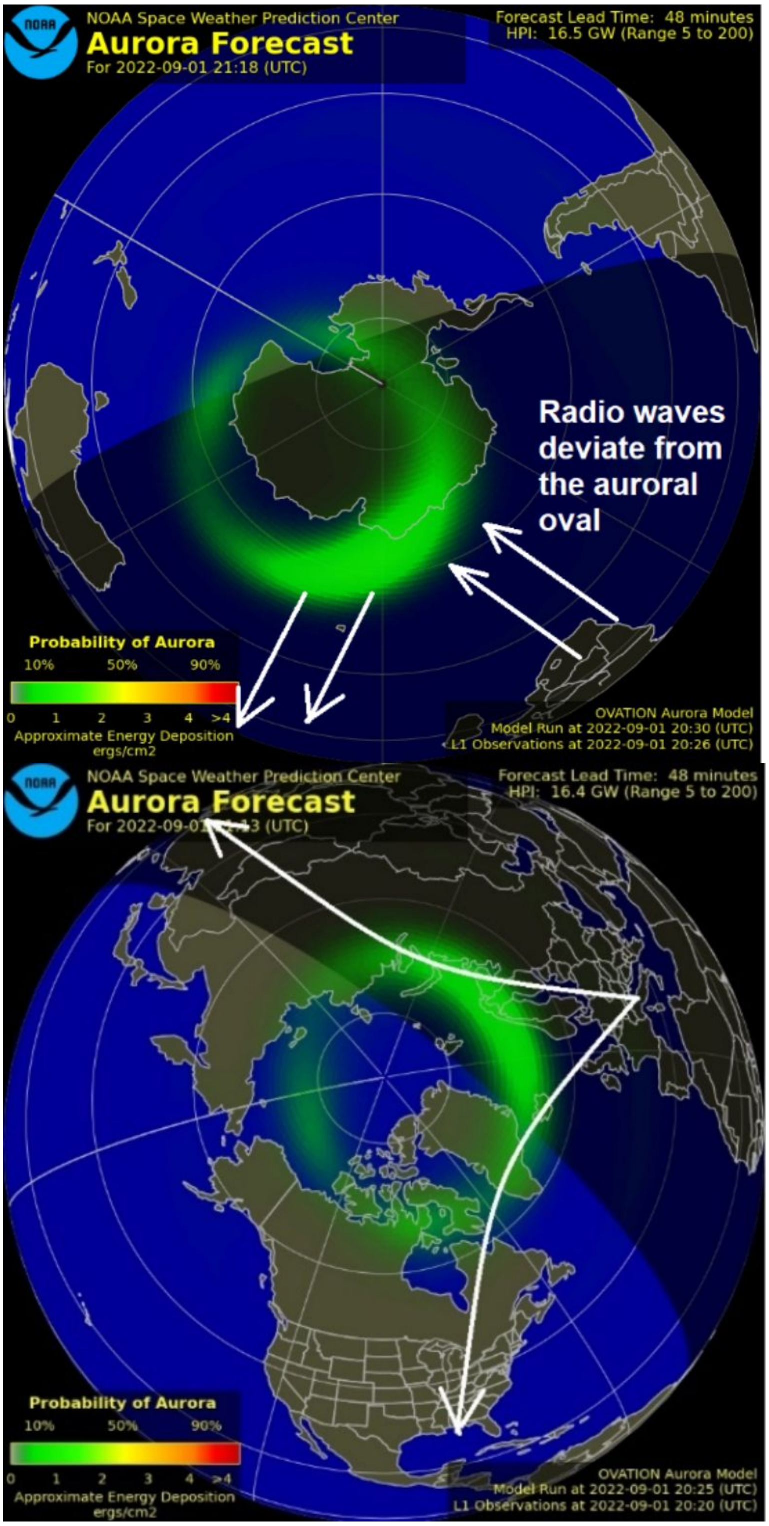


Image by NOAA. (Public domain).

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Azimuth deviation to the South Pole

In some cases, by pointing antennas south, the connections to Australia are better.

The hypothesis is that there is some sort of lateral reflection on the Southern Auroral Curtain, when (as is the case for the North Polar region) because of the solar wind, the Southern Oval widens to 55° south latitude. A side occurs - scattering on ionized masses of great density such as auroral curtains, capable of diverting wave trains in transit.

Azimuth deviation to the South Atlantic

Another important deviation is that which can occur at the height of the Atlantic Ocean, can happen, pointing the antennas to south, south-west direction to connect the WMOs of South and Central America and in some cases also the Coast of the USA.

There may be some sort of deviation introduced by the South Atlantic Anomaly, wave trains could be diverted westwards to ionized masses influenced by the Inner Ring of the Van Allen bands that in this area approaches the Earth's Ionosphere.

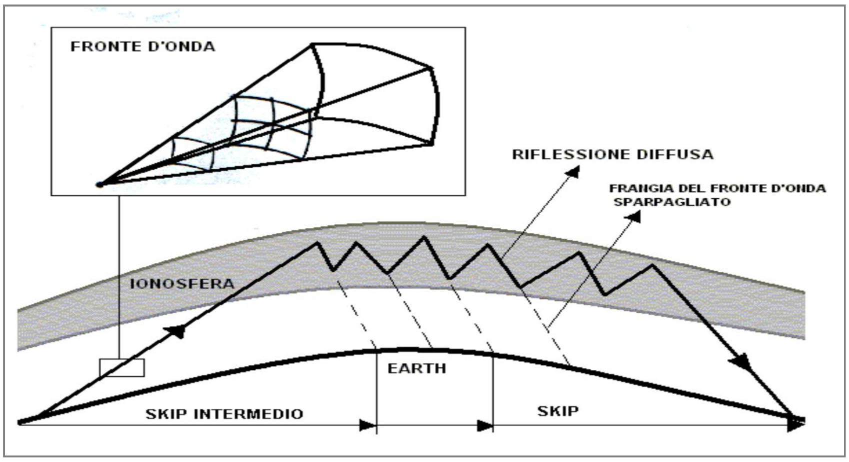
Map created using the DX Atlas software, www.dxatlas.com.

The deviation to the East Coast of America could be caused by the equatorial anomaly, the

southbound wave trains, they may encounter in the magnetic equator belt, an agitated ionosphere operating side-scatter. The equatorial electrojet and the approaching radiation pressure of the sun can cause that inclination of layer F that sends signals back to the East Coast of America. The map at the top right illustrates the possible deviation introduced by the equatorial anomaly, positioned above the Atlantic Ocean, the deviation is not systematic anyway, but depends on the geomagnetic situation and the position of the terminator, the deviation band should be located along the equatorial belt of Africa to the Atlantic Ocean following the magnetic equator line. We know that in the terminator zone, at low latitudes, a large ionization zone formed by cigar form clusters of ionized electrons accumulates from the illuminated part to the dark part is formed because of solar radiation pressure, this ionized mass can deflect signals. (Image by Wikipedia public domain).

Widespread reflection

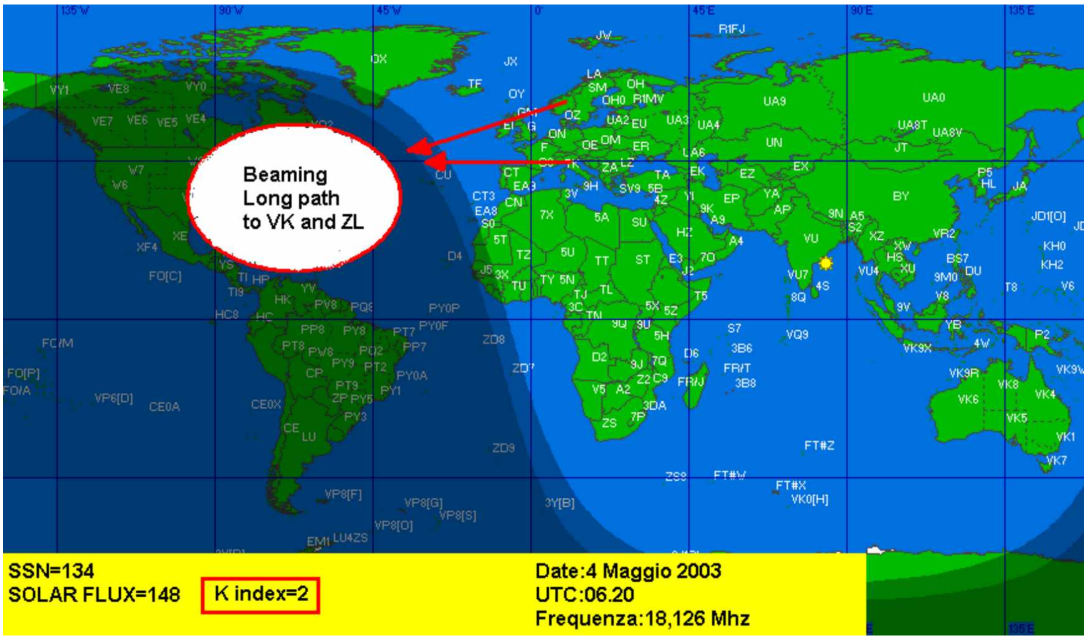
The dynamics of azimuthal deviations are even clearer if one considers the already mentioned theory of diffuse reflection. The wave front, a few thousand kilometers from the antenna has an exceptionally large surface area (the energy propagates according to a sphere), the successive ionospheric curvatures, cause much of the energy returning from the ionosphere, descending towards the earth, not proceeding according to a line (as the theory would like) but already curved and oriented to go up towards F layer.



A part of this signal that gradually widens, reaches the ground at 3000 or 4000 kilometers and allows reception in every location whose distance is beyond the "area of silence", but it would only be a fringe of the scattered wave front. Thinking about this concept exposed by Marino Miceli, we understand and justify better the abnormal azimuthal deviations of the signals, a wide and scattered wave front lends itself better to a deviation introduced by any ionospheric anomalies encountered along the way.
The systematic observation of propagating phenomena, leads me to think more and more, that the idea of widespread reflection propagation is the closest to reality, in fact the so-called "shadow zones" are never well defined, just as the Dx signal is picked up at various distances along the way, in a more or less strong way (this depends on the conditions of refraction spread along the way), I remember that the width of the front of the energy radiated a few thousand kilometers from the source is frighteningly large since the dispersion of electromagnetic energy increases with the square of the distance, unless you introduce the concept of the wave guides that could carry the wave front, with low losses, at great distances, but this is another discourse, which we will delve into in another chapter.

Anomaly on the long path

I find it interesting to report a propaganda anomaly that I encountered on the 17-meter band on the morning of Sunday, May 4, 2003. Propagation open via Long path to Australia, as confirmed by the excellent signal of his friend Gerry, VK7GK that transmits from the island of Tasmania and that arrived with an excellent signal (5/9+), for the long way. At 6.20 utc, I listen to a station from Norway looking for connections to Australia, lor listening with my antenna pointed for the long way, which for Norway corresponds to 250° azimutali. Interesting to note that the Norwegian station got to me at 5/7, "looking for it" with my 270° antenna. Pointing the Yagi northwards, for Norway, the signal dropped drastically to S1. In the map below I reconstructed the situation I have just mentioned, including the position of the terminator and the geomagnetic indices. At this point it becomes difficult to explain this propagating anomaly.



Map created using the DX Atlas software, www.dxatlas.com.

Returning to the concept of diffuse reflection and the possible wave guides that form when the solar-geomagnetic situation allows, the phenomenon could be explained by the possible propagation for ionospheric wave guides, the signals could enter these areas and therefore the reason for lateral propagation to Norway could be explained, which geographically is exactly to the north. It must be said that the signal was linear, it was not subject to scintillation or echo effect.

D layer peak density

In the figure below (azimuthal map), I reported the path for the long way that develops mainly on the side in darkness. Therefore completely outside the attenuation zone of region D highlighted by circular lines. Reflecting on the dynamics of the connection it is possible that the northward propagation was closed or very poor and that vice versa the propagation to the west was good. In light of this, the westbound wave trains may have met in a common volume in an area of the Ionosphere where the MUF rose abruptly.

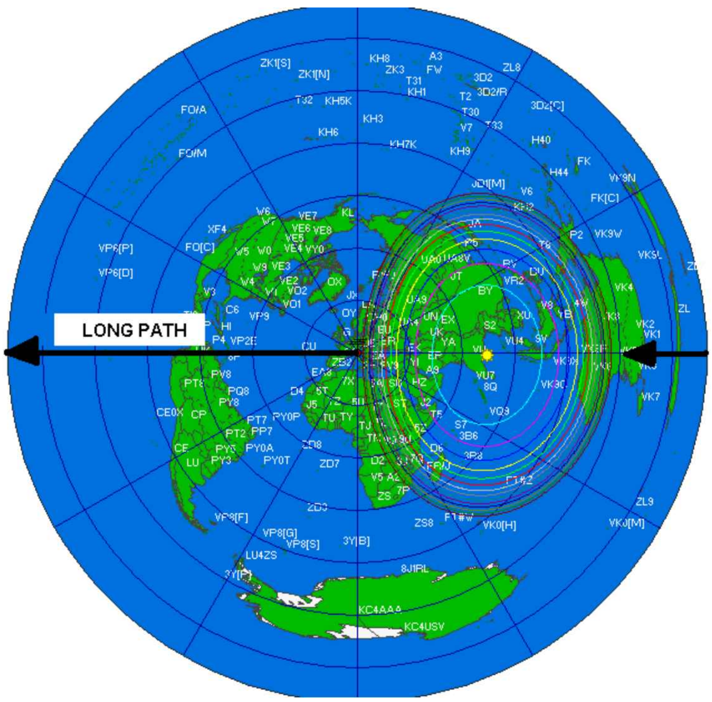
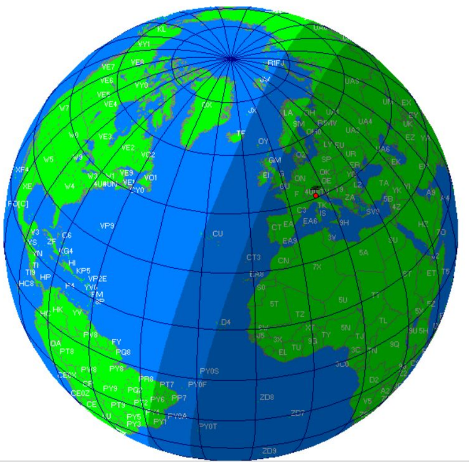


Fig. The long path to Australia, which develops on the dark side, completely outside the attenuation zone of region D, highlighted by the series of concentric circles, and corresponding to the sunlit area. Map created using the DX Atlas software, www.dxatlas.com.

Azimuthal errors in HF propagation

Introduction

This study aims to investigate a phenomenon that I have encountered several times on the HF bands and which I have called "Reflected Propagation". I inspired by an experience on the 17-meter band made on the evening of April 17, 2004, around 10.40pm local time. The band was open to the illuminated side of the globe, with signals mostly from Central America. On the frequency of 18.131 MHz, the OM3LZ station was audible, from Bratislava radiating towards the west, looking for connections with Central American stations. At 22.42 HK4CZE answers, Jorge from Medellin - Colombia who arrived with a signal around S3. Once again, the Slovak station was only listenable by pointing my antenna towards Central America. The OM3LZ signal came from a direction of 270 ° azimuth, precisely the direction of the best propagative aperture. This phenomenon is much more frequent than what is believed and could explain at least in part what is reported by many ham radio who argue that very often the quality of the signals arriving on the directives are not always consistent with the geography, in other words with the real direction of the correspondent.



Hypothesis

Inside the Ionosphere, favorable directions are created for the propagation of signals, the confirmation of this is that HF propagation is very selective and possible only in certain directions, this selectivity is determined primarily by the movement of rotation of the Earth and consequently by the continuous and progressive variation of solar radiation. High ionization areas are created, where MUF are favorable and sometimes wave guides that support propagation. It is within these propagating areas where there are significant variations in the ionization gradient between one zone and another, that we must look to try to find the nature of this phenomena. Within these areas and therefore, the signal can undergo such reflection that pointing the antenna in the correct direction, is picked up without problems. In this specific case, it is possible to speculate (1) on the terminator line, which was located on the Atlantic, at the height of the Archipelago of the Azores. This anomaly is similar in some respects to the phenomenon known as "Back scatter" (2), but it should not be this, because back scatter is supported by a scattering of the signal due to reflection on the ground. Sometimes, however, especially when the frequency of the signal is less than or close to the MUF, the two phenomena can occur at the same time making it difficult to distinguish what really happens. The data collected so far are in fact enough to formulate this hypothesis on the mechanisms of "Reflected Propagation", but there are still not enough certainties to formulate a theory.

It should be considered that the reflection surface (3) about 2000 kilometers from the transmitting antenna, is huge, in the order of one million and more square kilometers. The reflections introduced by iz2esv shift the discussion to other aspects of HF propagation. The morphology of the territory, for example, or the local weather situation, can influence the medium that supports propagation, even in the case of decametric

waves, rightly iz2esv proposes an interesting analogy with propagation in VHF and introduces the discourse of ion curtains of which we find for example a high concentration along the terminator line.

Listening data:
Date:17/04/2004 Time: 20.42 UTC Frequency: 18,131 MHz
OM3LZ Bratislava -Slovakia signal received: S7Angolo antenna pointing: 270°
HK4CZE Medellin -Colombia signal received: S3Angolo antenna pointing: 270°

Propagation test with HA8JV

Even more significant is the test carried out with a Hungarian station, Ha8Jv, my friend Paul who transmits from Bekescsaba in the south-eastern part of Hungary at a distance from my qth of 750 kilometers. The tests conducted with Paul seem to support the hypothesis of a reflection on ion curtains produced by the solar radiation pressure on the grey line. The first test was done by pointing my antenna at 270° azimuthal, the same direction as Paul, who was looking for connections to South America and the signal was S7. The second test was done by turning the antennas of both, towards North America and then at about 310 ° azimuthal, the signal was confirmed with the same intensity of S7. The bilateral connection was therefore possible only by exploiting the "reflected propagation" and exploiting with their antennas the same reflection surface, the intensity of the signal gradually followed the respective pointing of the antennas towards the reflection surface, while it was impossible with the antennas directly to Hungary. See the map below that best displays the mechanism. The propagation to the east, in darkness, was in fact closed. HA8JV, radiated with 4 quad elements and about 200 watts, the test was done at 19.50 UTC on 18,133 MHz on 22/04/2004.

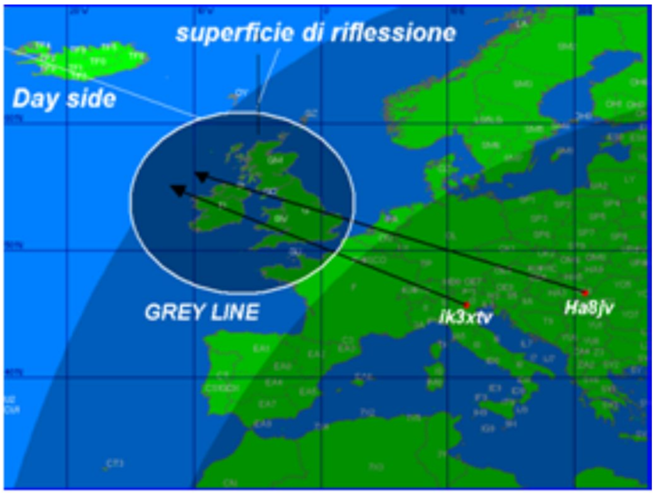
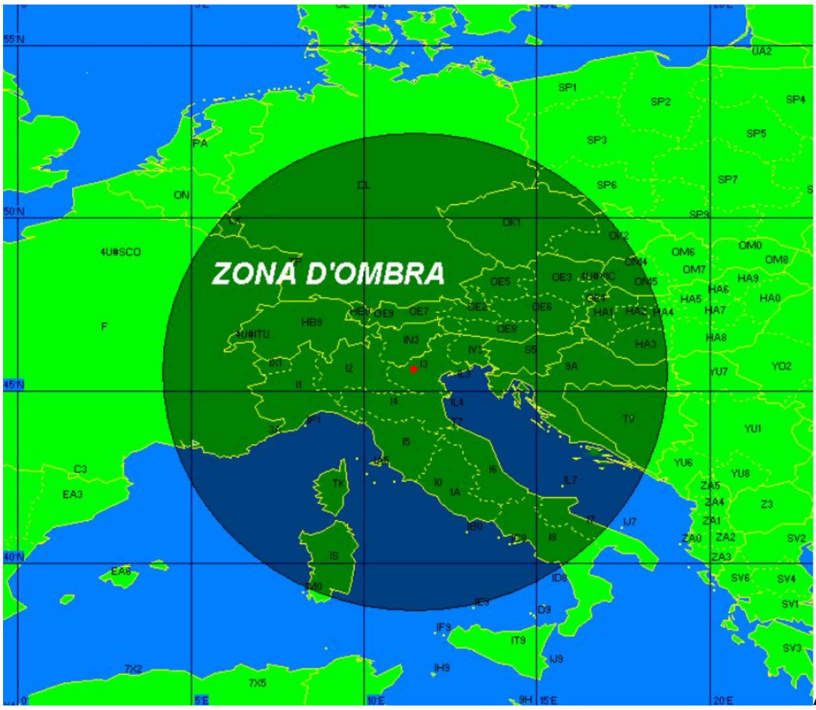


Fig. Map of the connection with HA8JV, with the antennas of both pointed towards the UK.
The signals propagating from Europe in a westward direction, after about 2000 kilometers, meet an ionospheric area where due to the radiation pressure on the terminator line, there are large irregularities in the ionospheric plasma, able to reflect the signals as a huge parabolic mirror.
Map created using the DX Atlas software, www.dxatlas.com.

Propagation test with ON5GW and RU9VR



Another test conducted on the morning of 27/11/2004 at 0800 UTC on 18 MHz always confirms the hypothesis of Reflex propagation. The Belgian station ON5GW connected a Russian OM RU9VR that transmits from the city of UFA to Asian Russia. RU9VR arrives directly at 60° azimuthal with signal of 5/9, while ON5GW is listenable 5/5 but always with 60° antenna, then eastwards. The Belgian station was not audible with the antenna pointed at Belgium. Here, too, we have confirmation of a Reflected Propagation from the area where the MUF is greater than 20 MHz, as shown in the figure below inside the cone drawn in black. Ru9VR's signal arrived without echo while ON5GW arrived with a very weak echo (the skip with Belgium is about 800 km) confirming that the echo effect gradually decreases with distance.

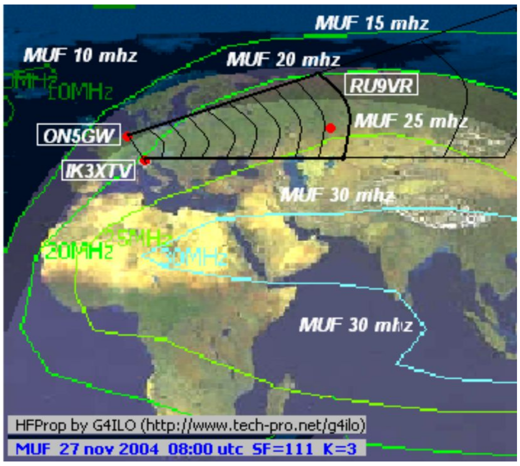


Fig. The figure on the left shows the situation of the test conducted with ON5GW and RU9VR, it is a map that shows the MUF in the Europe-Asia sector reconstructed based on solar and geomagnetic data using the HFPROP program. The figure on the right shows the shadow zone for the frequency of 18 Mhz. The width of the shadow zone varies with geophysical indices and consequently with the quality of propagation, I estimated an average value of about 500 km radius, based on my operational experience on this range. The phenomenon of reflected propagation occurs only for those stations located within the shadow zone (4) - See notes, for stations outside the shadow zone, the directions of pointing of the antenna are those of the conventional ones. The connection with ON5GW was only possible with the antennas of both points to Siberia to connect RU9VR.

Image source: Propagation prediction software G4ILO, elaborated by the author and Dx Atlas software by Alex Shovkoplyas, VE3NEA

Propagation test with OK2ZW

On the morning of Saturday, November 20, 2004, I had the opportunity to perform tests with Zdeno, OK2ZW that transmits from the Czech Republic with a large antenna of 8 elements log periodic. Ok2ZW's signal was subject to an extraordinarily strong echo. From field observations, the echo effect from nearby stations (located within the hypothetical shadow zone) is more pronounced when long path propagation is open, in fact, Zdeno was connecting many Japanese for the long way. The tests conducted confirmed that the echo becomes much more intense when both antennas are pointed in the short way direction. When pointing the antennas for the long way, the echo attenuates strongly, to disappear. The hypothesis is that the OK2ZW signal came either by long-distance propagation or backscatter effect, with the latter being the predominant component, or, why not, a combination of both.

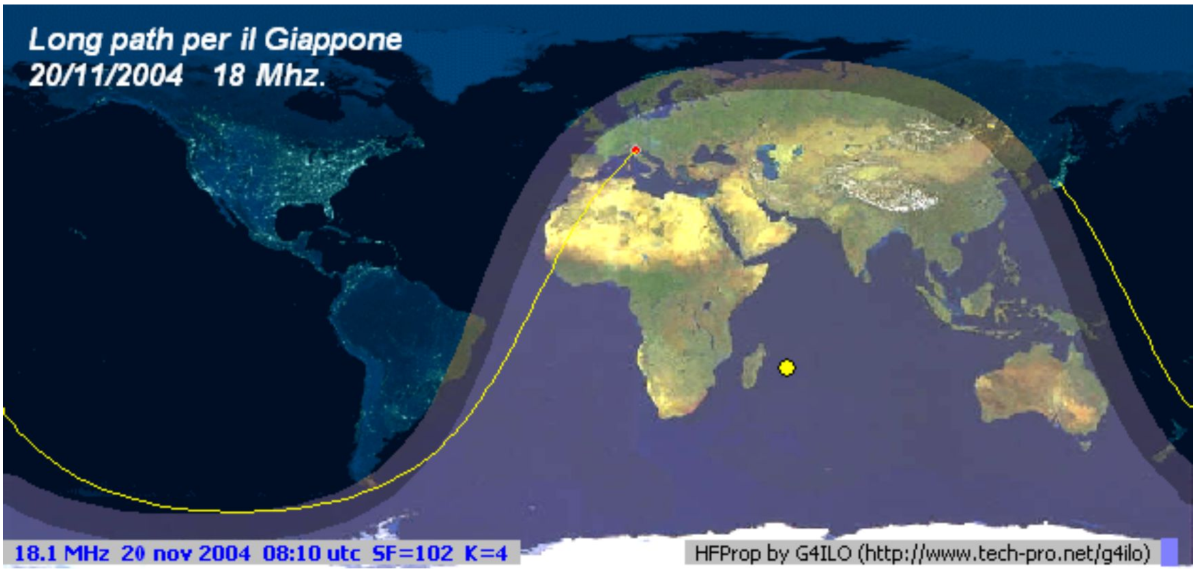
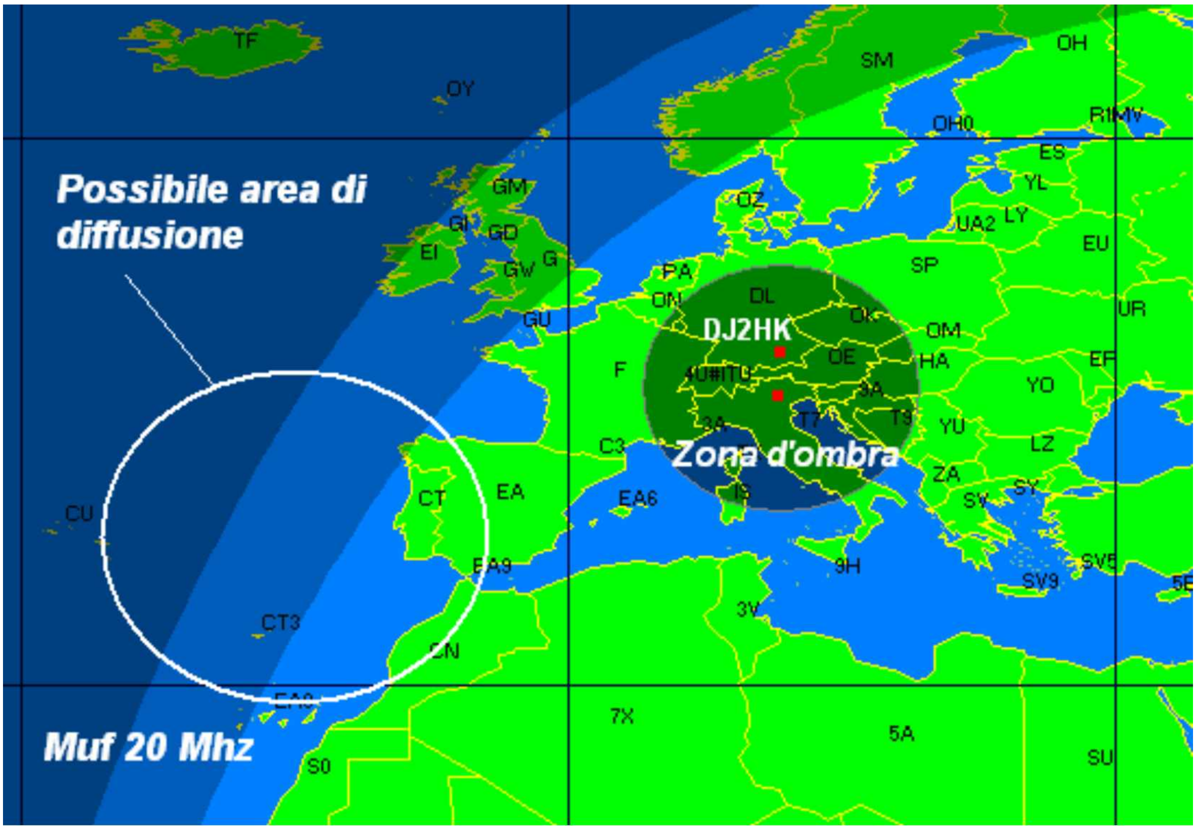


Image source: Propagation prediction software G4ILO, elaborated by the author.



Propagation test with DJ2HK

Another significant test comes from listening to the German station DJ2HK, transmitting from Munich, on the other side of the Alps 270 kilometers from Thiene. This is a further confirmation of what has been said about stations within the grey area. The signal was plagued by slight sparkle and came from 230-240° azimuthal, a deviation of 130° from the direct skip, from a direction therefore opposite to Bavaria. The listening data are as follows: 07.40 UTC of 25/11/2004 signal S8, on the frequency of 18 Mhz. It is difficult in this case to establish a reflection along the terminator, which at that time was above the island of Madeira, or on a terrestrial surface.

The map shows the possible area of localized diffusion between Morocco, the Canary Archipelago and the Iberian Peninsula, along the terminator in an area where the MUF are stationed around 20 Mhz. Another explanation for the

phenomenon could be a back scatter on the Iberian Peninsula or along the coast of North Africa. In that area the conditions, they had to be very favorable.
The phenomenon of back scatter often occurs when MUF rise significantly. Map created using the DX Atlas software, www.dxatlas.com.

Note:
Reflected and Backscatter propagation.
It is hard to distinguish the propagation I called "Reflected" from the Backscatter.
The substantial difference is that in the Backscatter, the signal scintillation is significantly more evident.

Signal scintillation

The signal supported by the phenomenon of "Reflected Propagation", as well as the signal due to Back scatter is characterized by scintillation or flutter fading, the American OM call this phenomenon Hollow sound, literally translated: sound from cavities, hence precisely the mentioned effect. The practical observation seems to confirm that the effect increases progressively when the corresponding one is closer. This is a very rapid fading, due to ionospheric irregularities. However, this does not seem entirely credible. Variations are too rapid to be caused by simple movements of these irregularities. I remembered what Marino Miceli wrote, I4SN several years ago on the pages of "Radio Rivista" (*Radio Rivista 2/90 - La Ionosfera*), the hypothesis reported by Miceli, is based on a theory formulated by Prof. Rumsey of the University of California San Diego. This theory explains how scintillation depends on a space-time fluctuation of the Ionosphere refractive index. The deviation of the refractive index from the average value can trigger the phenomenon, a small slippage is enough. The refractive index of electromagnetic waves in the ionosphere depends on the electronic density, the same refractive index is strongly influenced by the magnetic field, and this is combined with the scintillation of those signals that propagate through the auroral zones (connections to the American West Coast).

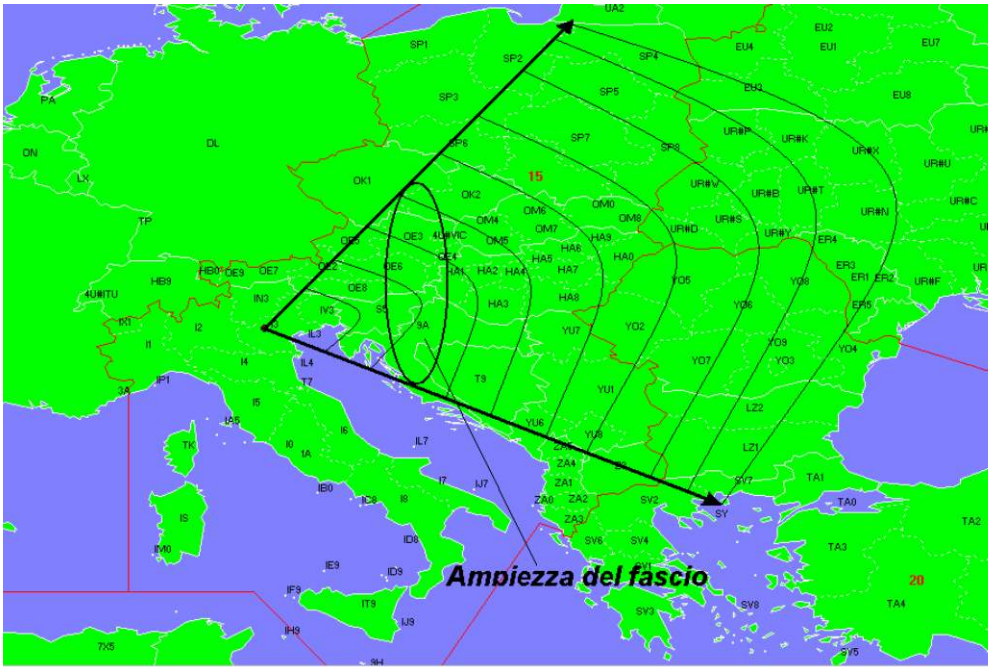
Sum up:

- <u>Auroral scintillation</u>: caused by variation in refractive index introduced by polar ionosphere instability

- <u>Scintillation on trans-equatorial propagation signals: The phenomenon occurs for those</u> signals passing the equator supported by evening TOP and caused

by the variation in the refractive index introduced by the instability of the Ionosphere along the magnetic equator line on the grey line

- Back scatter scintillation: due to the variation introduced by the refraction of the signal on the Earth's crust



- Reflected propagation scintillation: caused by the variation in the index caused by the refraction of the signal on the ionosphere to the terminator or other irregularities of the ionospheric plasma.

Fig. The beam width of a directive antenna for HF, is less than 60 °, this means that the part of the ionosphere hit by the signal radiation is large and directly proportional to the distance of the emission point. Inside this sector the ionosphere has many irregularities. It is presumed that inside this large area, following the theory of Rumsey, it is extremely easy to find the conditions for a deviation of the refractive index. Thus, the phenomenon of Hollow sound occurs. These conditions, for example, occur in the auroral zones, in the presence of strong excursions of the geomagnetic field and in the case of reflected propagation. In the latter example, the deviation of the refractive index should be caused by the unstable refractions that occur on the ionosphere at the terminator.

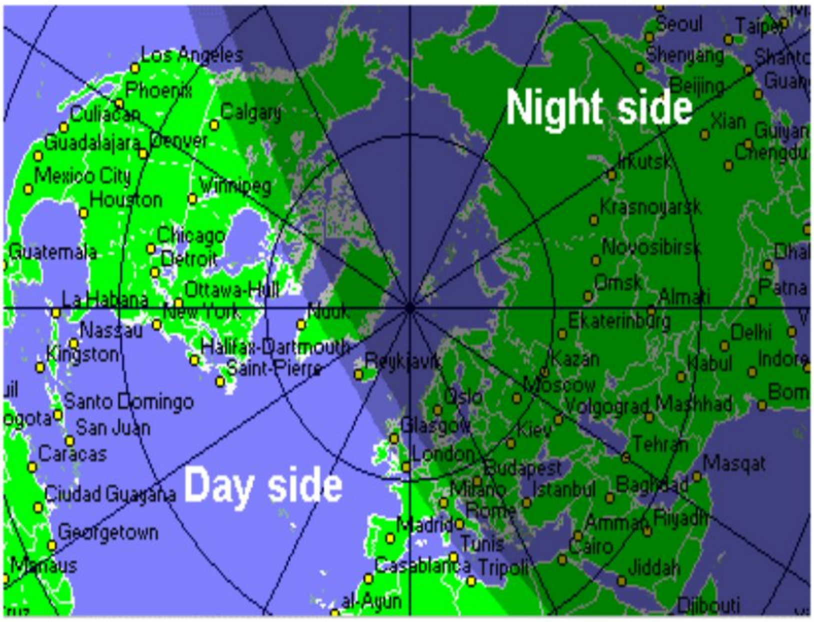
Map created using the DX Atlas software, www.dxatlas.com.

Backscatter

The phenomenon of back scatter propagation often occurs when the MUF rise significantly.

The signals are characterized by an unmistakable sound, like a rumble (hollow sound) and are never very strong signals and almost without any fading effect. The effect is due to reflections of the signal on the Earth's surface, and specifically on mountain ranges, desert area of sand, or on bodies of water, usually on surfaces that have different refractive indices, for this reason the phenomenon should be analyzed in relation to each individual geographical position. In my case, the position close to the Alps range becomes on the one hand penalizing and on the other difficult to interpret due to refractories in the mountains. The phenomenon of back scatter is accentuated as the frequency increases. There are specific observations and research made many radio amateurs, which confirm a lot of QSO, supported by back scatter propagation, due to refraction on the Sahara Desert or from the Ural chain in Russia. Another explanation for the phenomenon comes from the diffusion in many directions by the sea surface, a small part of the diffused signal returns to the transmitter:

two stations between 100 and 2000 km, pointing in the same direction, towards the diffusion zone, can be heard even if the direct path is too short.



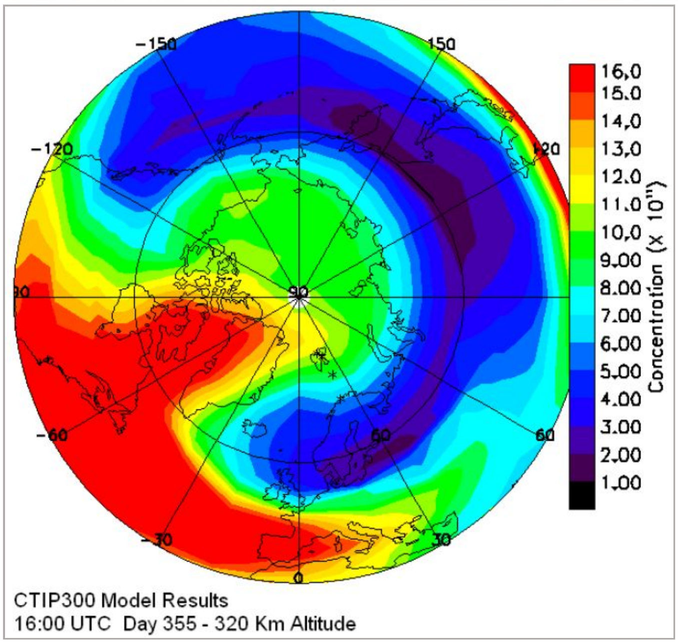


Fig. The systematic observation of the conditions on HF bands leads me to think how the electronic concentration in the ionosphere creates favorable directions or even waveguides, within which the signal finds a preferred route. The image on the left shows the electronic concentration at the F region (320 km), the map on the right shows the same situation (day 355 hours 16 UTC) that shows the position of the grey line. Note that the

electronic content is influenced not only by solar radiation, but also by the particle precipitation that occurs in the auroral oval. Map created using the DX Atlas software, www.dxatlas.com.

Propagation test with JA5AUC (Long path echo)

Remarkably interesting is the test conducted with the Japanese station JA5AUC as it provides valuable information about long path propagation and especially about the strong echo that plagued the signal. Always, long path signals are characterized by this effect, which is further accentuated, when propagation is open on both the long and short path. For this specific case I did some simple mathematical calculations. Considering that the long route measures 30616 kilometers and the short 9387 the delay in propagation between the two routes is considerable and equal to about 70 ms. Such a delay is enough to introduce a considerable echo effect on the signal. Given that in certain favorable circumstances the wave train can also make the entire circumference of the earth more than once. Although I do not have a numerical measurement of the delay on the JA5AUC signal, we faced with a similar case.

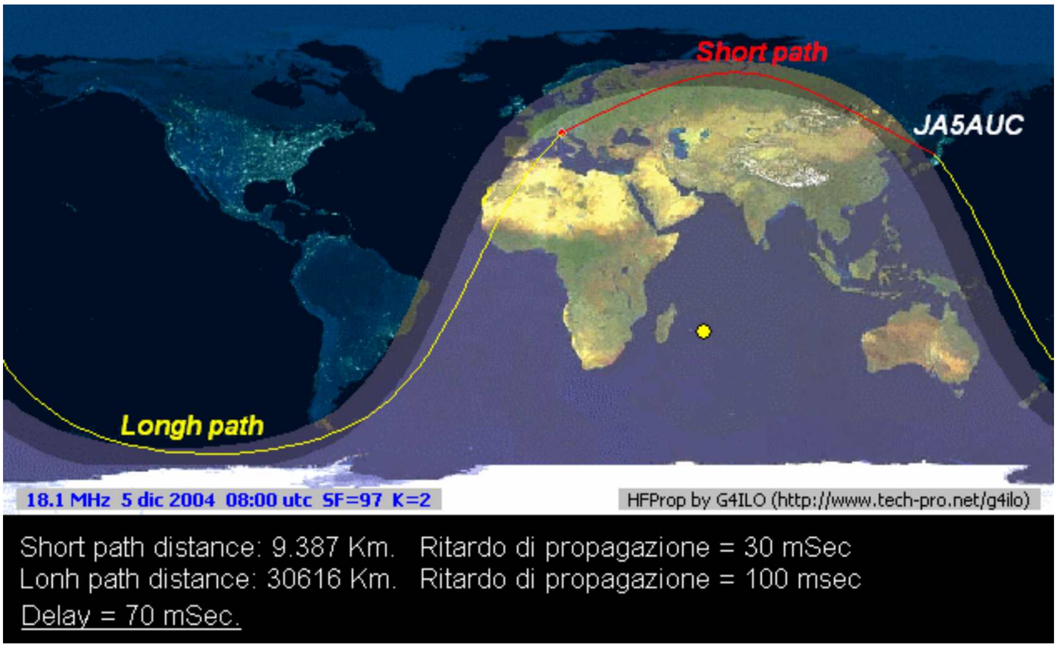


Fig. In this image, I reconstructed the path of the signal showing both the long and the short path, both sections

develop practically following the profile of the *grey line, with propagation in both directions. I do not think it is by chance. The small auroral oval favors the connection that especially on the path along the south pole. Aurora's level was 3, i.e., low.*

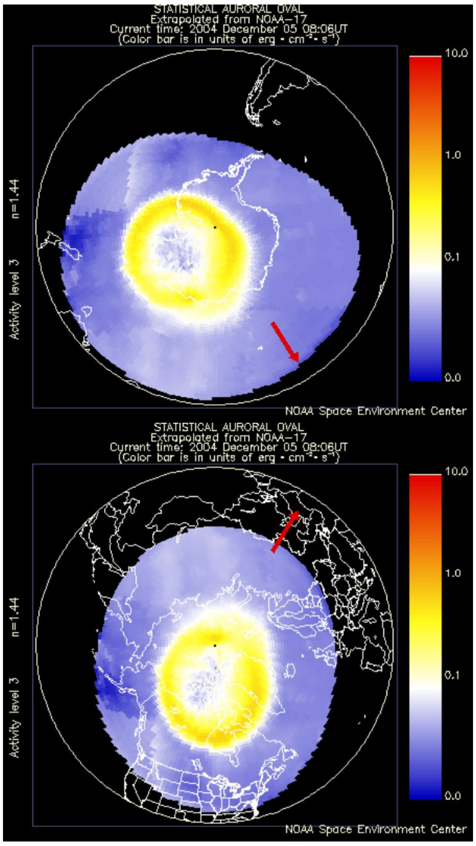


Fig. Situation of aurora level, northern hemisphere and southern hemisphere. Activity level of 3 (low).
Image by NOAA.

<u>Notes:</u>

1) SPECULAR REFLECTION: Reflection of the signal due to the curved ionosphere, because of radiation

pressure the ionosphere and the earth are not two concentric spheres, therefore a continuous deformation takes place that is accentuated near the terminator, therefore oblique surfaces are formed with respect to the ground or even curved surfaces that can also focus the signals.

2) BACK SCATTER: In some cases, when ionosphere conditions allow, two stations within the shadow zone can be heard because of back scatter or side-scatter propagation. When the frequency of the transmitted signal is near the limit of the MUF, it is reflected to the ground in region E or F, but part of this emission is reflected in an area shared by both stations, and within the theoretical shadow zone. The signal appears very modulated and easily recognizable since it appears free of evanescence but characterized by a strong echo effect.

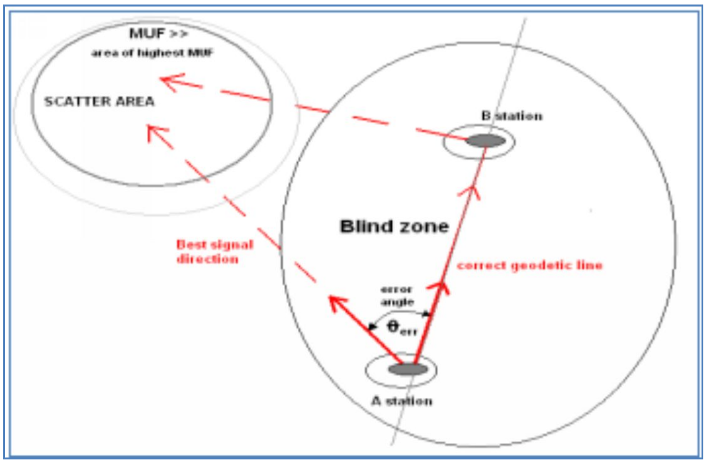
3) REFLECTION SURFACE: Taking for the convenience of representation a directive antenna, its irradiation beam is not less than 60°, this means that the reflection point at a distance of at least 2000 kilometers is an ellipsoid whose major axis is at least a few thousand kilometers long with the consequence that the reflection surface is an area of at least 1 million square kilometers.

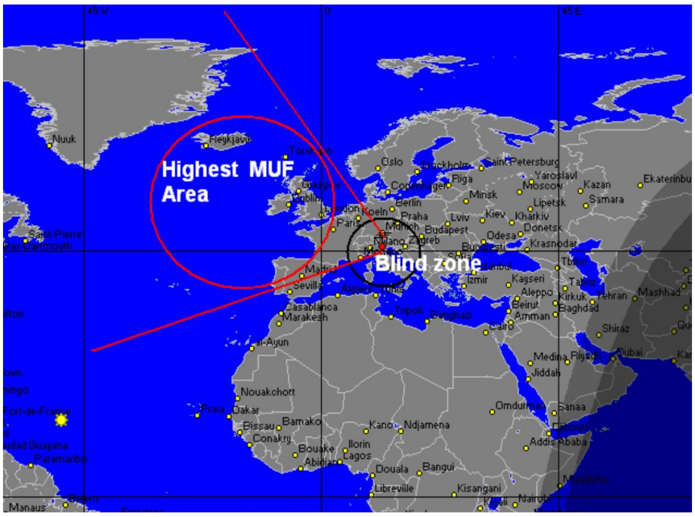
4) SHADOW ZONE: It is the circumscribed area within a radius within which bilateral connection is not possible. The breadth of this area depends not only on frequency but also on the quality of propagation. The chart below shows a graph showing the radius of the shadow zone for the 17-meter range based on the quality of the propagation.

Azimuthal errors: experimentation with Faros and WSJT

Introduction

The aim of this research is to study a phenomenon highlighted on the HF bands; it is a systematic pointing error towards some stations for which the signal arrives of greater intensity not from the correct direction of the corresponding qth but with a different antenna pointing angle (azimuth error). It is difficult to figure out exactly what causes this difference. It starts from the study of some experimental cases already described in an earlier publication and formulates some explanations. The tools used are the WSJT digital transmission system because it allows signal traceability and Faros software designed for listening to and monitoring NCDX Foundation beacons.



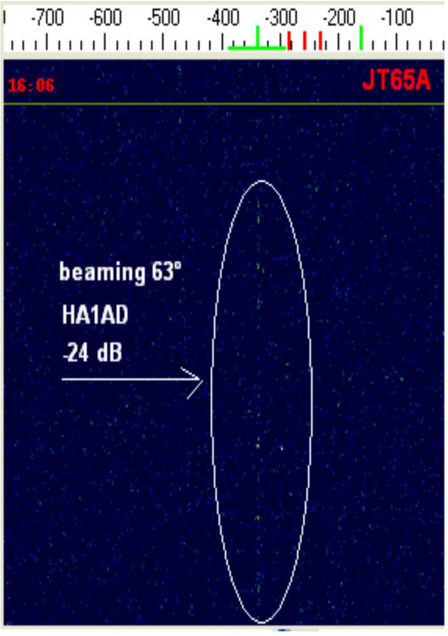
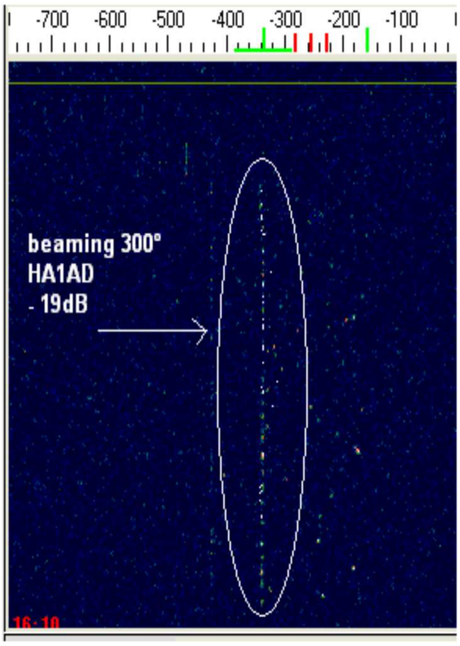


Highest MUF
Area
Blind zone

The hypothesis

Backscatter
Ionospheric scatter
Cutter effect

Small-scale irregularities and ionospheric ducts are clearly irregularities in the ionosphere which, as is well known, can support propagation in a more complex way than simple ionospheric reflection. In fact, local irregularities can have interesting effects, especially when they occur in large quantities. Long-distance propagation in the 6-meter range is often the result of a set of factors. Ionospheric scatter plays a role in many paths, many effects are positive, others negative. To understand how the scatter phenomenon takes place we have to imagine the situation different from the classic representation where the entire horizontal section of the ionosphere contributes to reflection. Ionospheric scatter has a different skip supported by a multitude of normally small reflective or refractive layers. The phenomenon then occurs when the signal encounters many cells. This mechanism can be thought as the refraction of an ionized gas bubble, the size of these cells can range from about ten meters to several hundred kilometers. When a wave meets one of these bubbles, it is scattered in all directions. Since the cells can be found at different distances from the point of transmission or reception, the signal arrives with different paths and therefore with a different phase and since normally the cells move in the ionosphere, a doppler effect is also added. There are two magneto-geographical regions where ionospheric scatter is more common. One in the magnetic tropics and the other near magnetic poles, In the tropics the phenomenon is associated with equatorial anomaly. The strong current moving electrons from region E and F1 to region F2, produces huge agglomerations of turbulent plasma that align with magnetic field lines.

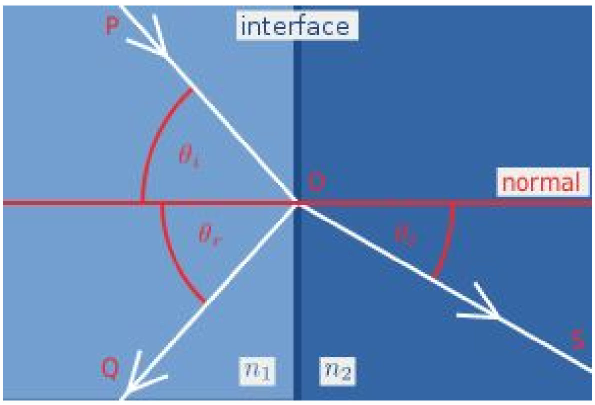

-700 -600 -500 -400 -300 -200 -100
16:06
JT65A
beaming 63°
HA1AD
-24 dB

-700 -600 -500 -400 -300 -200 -100
beaming 300°
HA1AD
- 19dB

The figure on the previous page, below, compares the experiment conducted with the digital transmission wsjt in jt65a mode with the Hungarian station HA1AD on 14,076 mhz. The azimuth to Hungary is 60° (dir. Northeast) while the signal was admissible with the highest intensity with the 300° antenna (dir. North-West). This is an example, even visual, of what has been discussed and seen
in the previous pages, about azimuth deviations.

These agglomerations are composed of a considerable number of plasma cells that produce significant scatter phenomena. In the case of the ionosphere tested by ionosonde to measure the critical frequency, instead of displaying a single layer F, the return echoes show a widespread area of echoes that starting from the normal altitudes of the F region extend up to 800 km in height: this condition is known as "Spread F". Scatter supported by the equatorial F spread intensifies seasonally at equinoxes and is almost canceled when the geomagnetic field is disturbed. We have previously talked about the presence of abnormal layers near the poles like equatorial ionospheric bulges, although the alignment in this case instead of horizontal, it is positioned vertically, along the magnetic field lines. We are also in this case in the presence of scatter regions supported by F spreads, again there is an intensification during the equinoxes with a decay in the summer and winter months. The phenomenon is intensifying in periods of maximum solar activity. The effect is responsible for metal modulation that often plagues signals passing through polar areas.

Fresnel's law

When light moves from a medium with a given refractive index n1 to a second put with index n2, both reflection and refraction of the light wave itself can occur. Let see the figure in the next page, where an incident light beam PO hits at point O the interface between two means with refractive indices n1 and n2. Part of the radius is reflected following OQ radius and part is refracted following the OS trajectory. The angles that the incident, reflected, and refracted wave form with the normal at the interface are in, θr, and θt, respectively. The relationships between these angles are given by the law of reflection and Snell's law. The refractive indices vary depending on the wavelength, so everything said so far must, be applied taking this into account. It should be noted that the discussion above assumes that the magnetic permeability μ is equal to the permeability of vacuum μ0 in both means. This is true in most dielectric means, but not for other types of materials. Fresnel's complete equations are therefore more complicated. In addition, for these laws to be applicable, magnetization M, electric field E tangential to the surface, and magnetic field B normal to the surface, are assumed to be uniform. The azimuthal error could therefore be due to something similar, where the interface between the two means could be traced back to the gradient difference (ionization) of two neighboring parts of the ionosphere



Backscatter: the theory

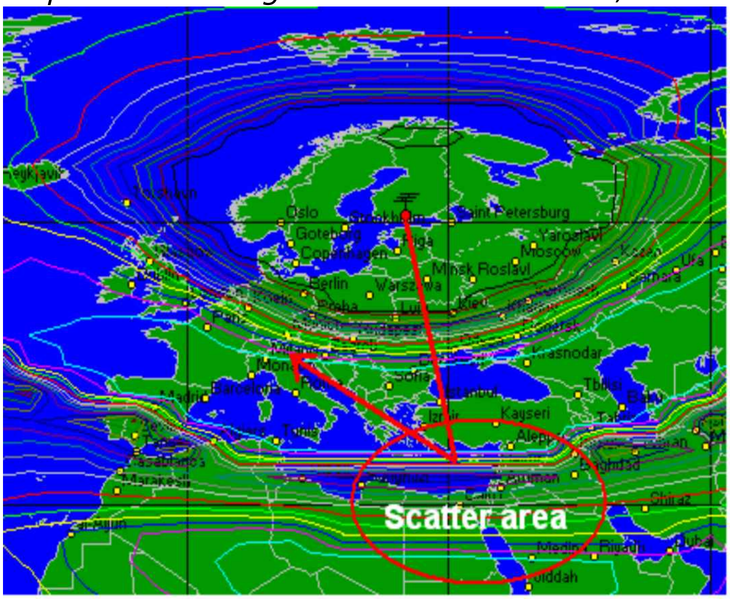
The phenomenon of backscatter propagation often occurs when the Maximum Usable Frequency (MUF) rises significantly. These signals are characterized by an unmistakable sound, resembling a rumble (a hollow sound). They are weak signals, almost devoid of fading. The effect is due to signal reflections on the Earth's surface, specifically on mountain ranges, desert areas, or bodies of water. These reflections typically occur on surfaces with different refractive indices. Consequently, the phenomenon should be analyzed in relation to each specific geographical location.
In my case, being situated close to the Alps range is both challenging and makes interpretation difficult due to potential signal refractivity in the mountains. The backscatter phenomenon becomes more pronounced as the frequency increases. There are specific observations and research conducted by various organizations that confirm links supported by backscatter propagation. This phenomenon can be attributed to signal refraction over the Sahara Desert or the Ural mountain chain. Another explanation for this phenomenon originates from signal diffusion in multiple directions by the sea surface. A fraction of the diffused signal returns to the transmitter. This explains how two stations located between 100 and 2000 km, both pointing in the same direction toward the diffusion zone, can be heard even if the direct path is too short.

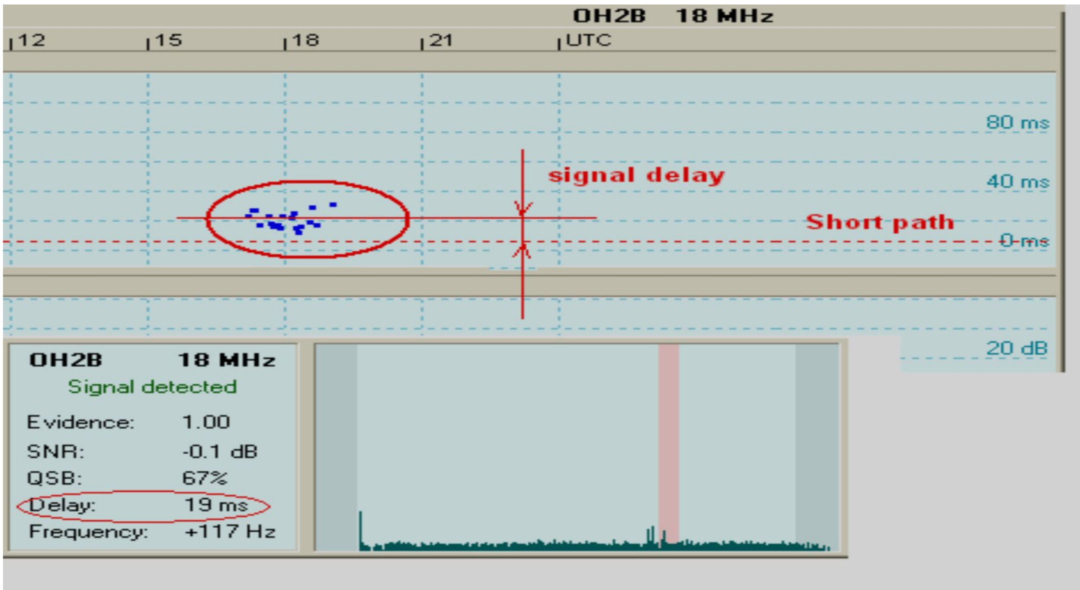
Experiments with the NCDX Foundation's OH2B beacon

The experiment was conducted in the 18 MHz band, during a time when direct propagation to Finland (OH2B) was completely closed, after 18 UTC. However, the beacon is clearly receivable via southeast, about 150°/160° azimuth. On the signal recorded with Faros, the average calculation of the delay is about 15 ms, compared to the short path, that is, the short path direction to the beacon. This is a path difference of about

4500 km. (Consider that an electromagnetic wave in 10 ms, runs 3000 km.) The hypothesis is of a reflection in the eastern Mediterranean area, at that hour, the area of greater ionization. The reflection could be located around the much dense ionosphere in this zone, or it could be reflected by the Mediterranean Sea, or by the Area of the Red Sea-Sinai. The experiment was also conducted in the 14 MHz band with comparable results, but with a larger opening time window.

Map created using the DX Atlas software, www.dxatlas.com.





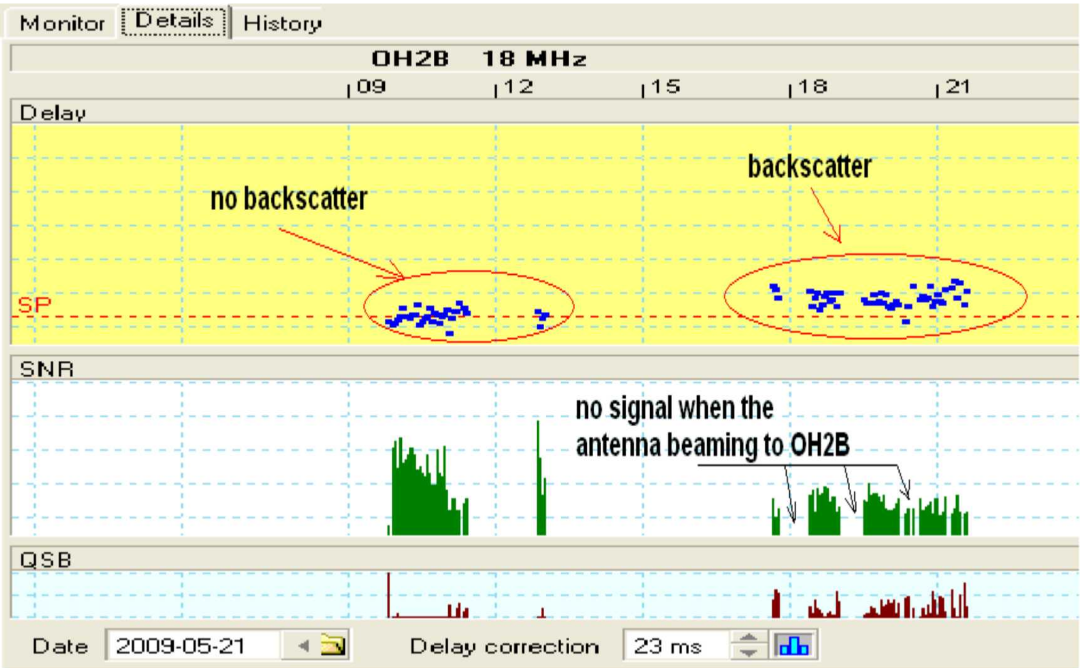

Monitor
Details
History
OH2B 18 MHz
09
12
15
18
21
Delay
backscatter
no backscatter
SP
SNR
no signal when the
antenna beaming to OH2B
QSB
Date
2009-05-21
Delay correction
23 ms

Fig. In the figure above, experiments with the FAROS software conducted on different days consistently highlight the backscatter phenomenon during the late afternoon and evening. The tests were conducted by alternating reception using a direct antenna (no backscatter) and an antenna pointed towards the scattering area (backscatter), as shown in the SNR green chart.Map created using the DX Atlas software and Faros software by VE3NEA. www.dxatlas.com.

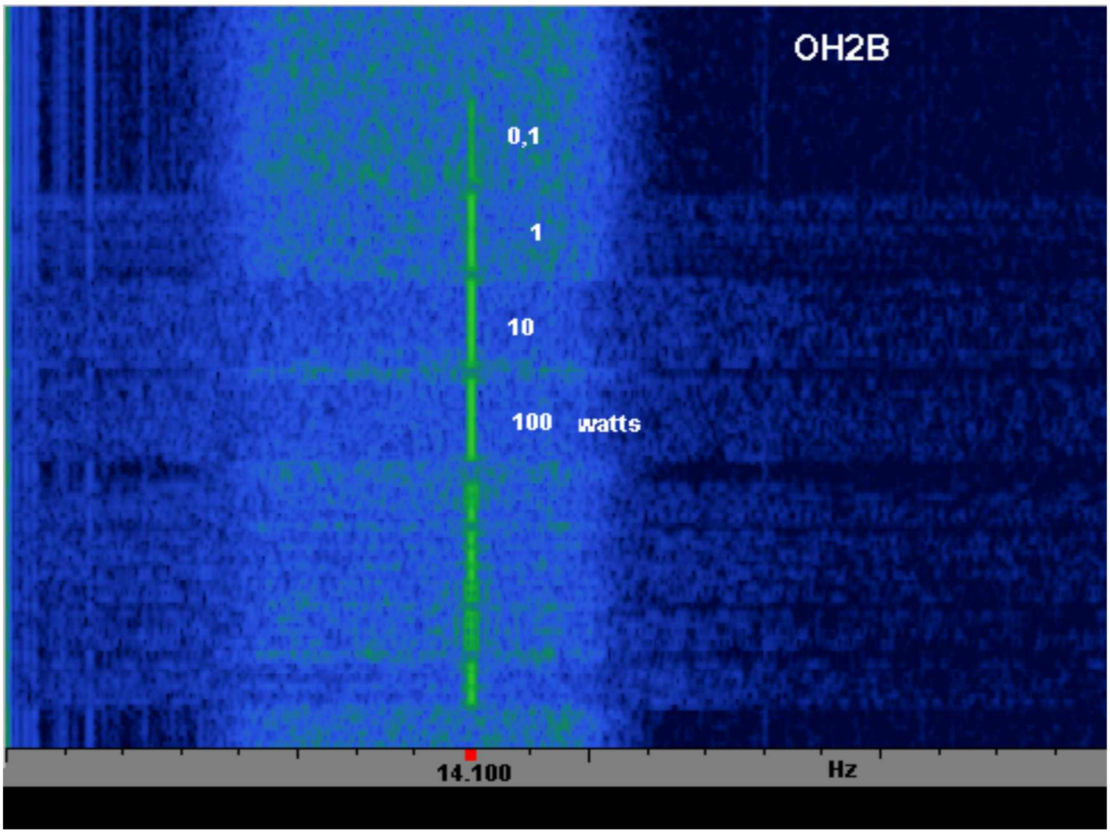


Fig. top: OH2B beacon signal spectrum. The beacon transmits the indicative in CW and then four lines of decreasing power. The first with 100W, then 10W, 1W and the last line with 0,1W.

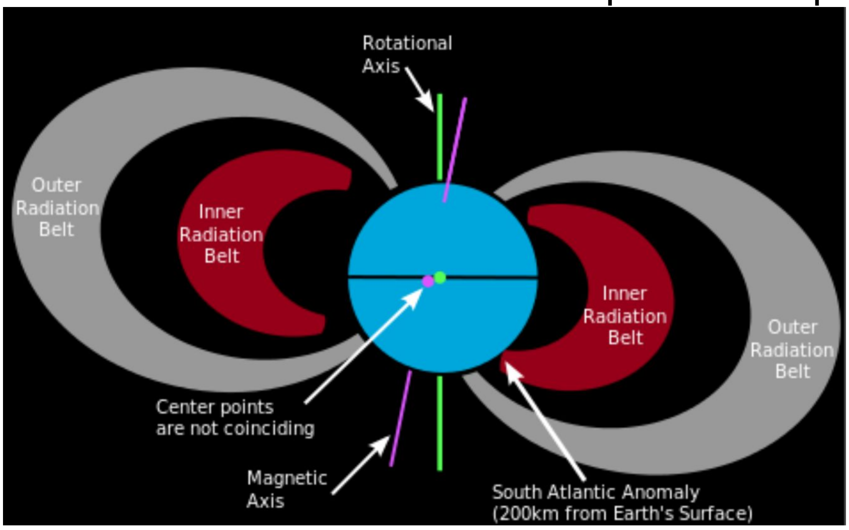
South Atlantic Anomaly

Introduction

The Earth's magnetic field, known as the magnetosphere, is indeed a crucial and fascinating aspect of our planet's natural environment. It is generated by the movement of liquid metals within the Earth's outer core, driven by forces such as convection, Coriolis, and gravity. This process functions much like a dynamo, creating and keeping the magnetic field that surrounds our planet. The importance of the Earth's magnetic field cannot be overstated. It enables compasses to function, providing essential navigation tools for humans and many animal species. Additionally, the magnetosphere acts as a protective shield, deflecting and trapping charged particles from the solar wind and cosmic rays. This protection is especially evident in the Van Allen belts, regions of charged particles trapped by the Earth's magnetic field, discovered by the Explorer 1 satellite in 1958.

Van Allen radiation belt

The Van Allen radiation belt are formed by an inner belt closer and an outer band farther to the earth, which is wrapped in it. Unfortunately, in a certain area, above the south Atlantic Ocean, off the coast of Brazil, the protection effect of the magnetosphere decreases as the inner belt of the Van Allen Belts approaches up to 200 km from the Earth's surface (see figure below), scientists explain this anomaly (called SAA, South Atlantic anomaly) as a consequence of the eccentric shift of the magnetic field from the geographic center of the earth that determines the displacement between the magnetic poles and the geographical poles of our planet and the difference between the geographical equator and the magnetic equator (the earth's magnetic axis is moved about 11 degrees with respect to the axis of rotation and the center of the magnetic field is out of phase of about 500 km from the earth's geographic center). In this area, in the South Atlantic, the protection of the magnetosphere decreases significantly so much that in space operations, the American Space Agency (NASA) must take this into account for the passages of the Space Shuttle, whose orbit in this stretch is more exposed to space radiation.



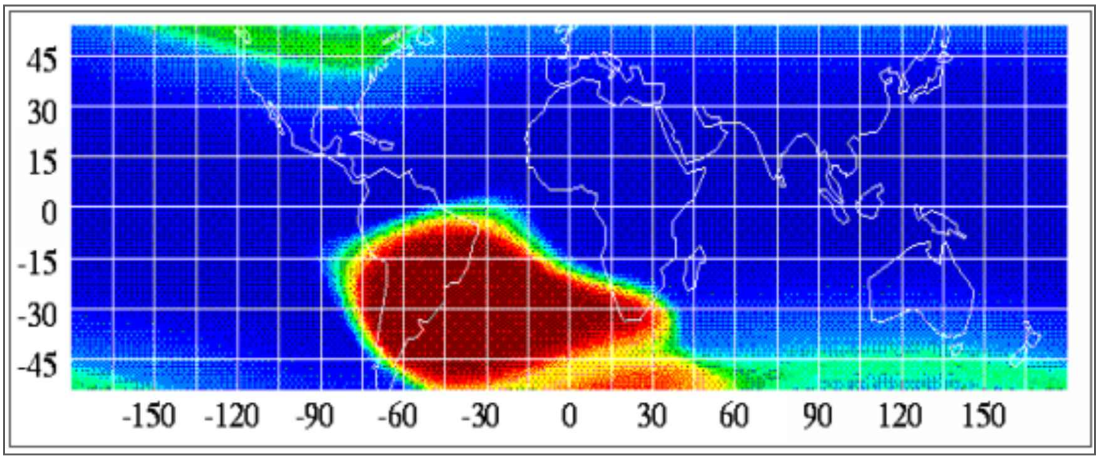
The figure above, shows the distribution of the Van Allen radiation belt around the earth and in *p*articulate the approach of the inner belt to *the earth's surface, called the South Atlantic Anomaly.*
(Image credits: Wikipedia public domain. Image by Marko Markovic-Wikipedia).

South Atlantic anomaly and propagation

There must certainly be a correlation between SAA (South Atlantic Anomaly) and radio propagation, when wave trains pass through this area, the Van Allen bands approaching up to 200 km, enter region F, where interacting with the Earth's ionosphere, affect its ionization and therefore the reflection of signals, there could be phenomena of super refraction or large azimuth deviations caused by sea. I have also discussed with other radio amateur colleagues who confirm to me phenomena of great azimuth deviations, for example QSO with the Hawaiian Islands pointing antennas towards South America, then a deviation for reflection induced by the SAA (a sort of "Side scatter").

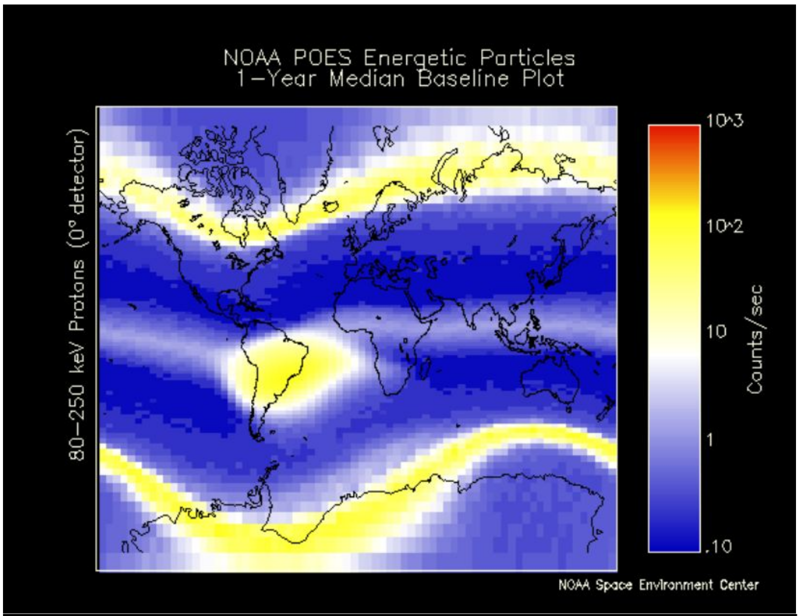
Geographical location

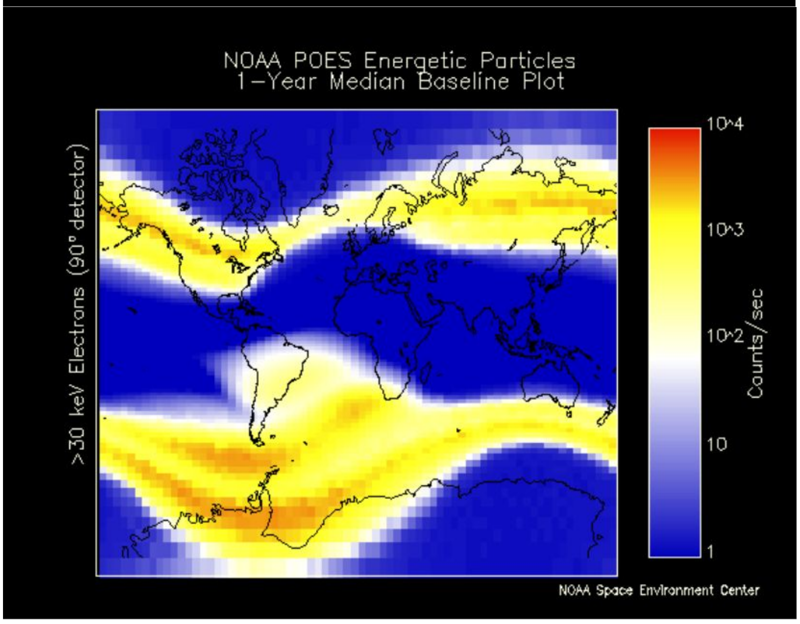
The map below shows the geographical positioning of the area within which signals in transit may be affected by the South Atlantic Anomaly, the extent of which, as is the case with the ionosphere and propagation phenomena, depends on the active solar and geomagnetic life, in certain solar-geomagnetic situations, the SAA could extend and influence propagation over part of South America.



(Image Wikipedia public domain. Image by NASA).

Energy particles
The illustration below shows on the left the concentration of protons (protons 250 KeV) revealed by the NOAA-POES satellite, on the right the concentration of electrons (Electrons 30 KeV) always from the
NOAA-POES satellite. This is an average of the data detected in a year.



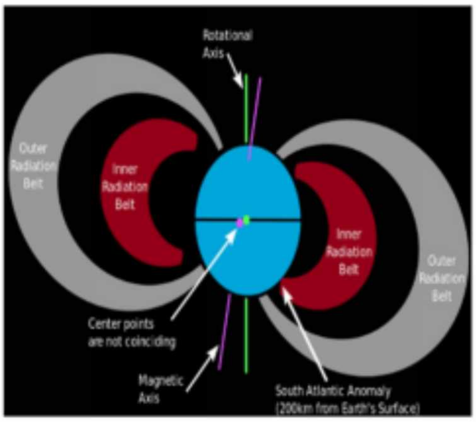


It can be noted (yellow areas) that the areas where the flow of energetic particles is most intense, are at high latitudes and this is due to the capture of particles by the converging geomagnetic field lines verses the poles, but a high "abnormal" concentration can be noted at the South Atlantic area, most likely due to the South Atlantic anomaly, from this image it is evident that the propagation in this air can have a behavior different from what one might expect.

Image: NOAA Space Weather prediction center.

The cause of the phenomenon:

In this area, the lower part of the Van Allen belts is closer to the planet's surface at the same altitude relative to sea level. The intensity of radiation in the Van Allen belts is higher compared to the rest of the Earth's surface. The Van Allen belts are symmetric with respect to the axis of the Earth's magnetic field, while this field is inclined by about 11 degrees relative to the Earth's rotational axis and offset by approximately 450 kilometers from the center of the Earth. These characteristics of inclination and offset of the magnetic field result in the innermost part of the Van Allen belts being closer to the Earth's surface over the South Atlantic Ocean and farther away over the Northern Pacific Ocean.



The misalignment between the rotational axis and the magnetic axis and the low altitude of the Van Allen belts over the South Atlantic (right side of the image)

The Ionosphere at high latitudes

Irregularly structured ionospheric regions can cause diffraction and scattering of trans-ionospheric radio signals. When received at an antenna, these signals present random temporal fluctuations in both amplitude and phase. This is known as ionospheric scintillation. Ionospheric scintillation may cause problems such as signal power fading, phase cycle slips, receiver loss of lock, etc., and degrade the quality of communication.

The ionospheric irregularities

The ionosphere can deviate from the expected behaviour, as for instance modelled by the Klobuchar model. This is the case when the ionosphere includes irregularities in which the electron density differs significantly from the “ambient” plasma. These irregularities can cause diffraction effects, i.e., scintillations, on the signals passing through them. The formation, evolution and dynamics of such irregularities are ruled by the interplay between the geomagnetic field, the Interplanetary Magnetic Field (IMF) and the solar wind (that is the emission of energetic particles coming from the Sun). During periods associated high levels of geomagnetic activity, patches of plasma 100-1000 km across with electron density enhancements of up to a factor of 10 above the background densities have been seen in the high latitude F-region ionosphere. The electron density gradients associated with large scale electron density structures form tilted reflection surfaces for HF radio waves which allow off great circle propagation paths to be established between the two correspondent stations.

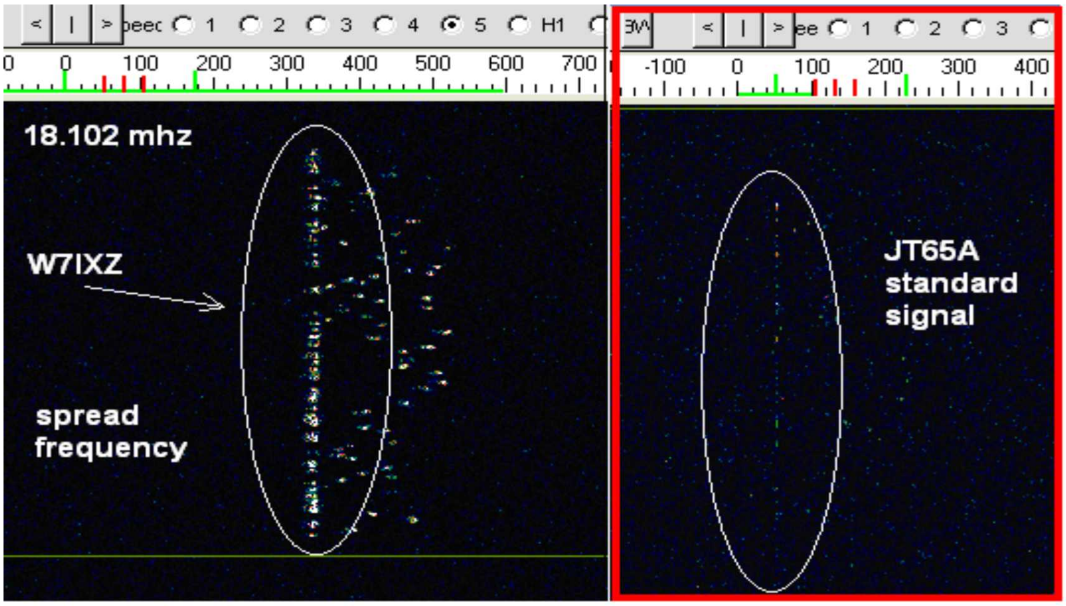
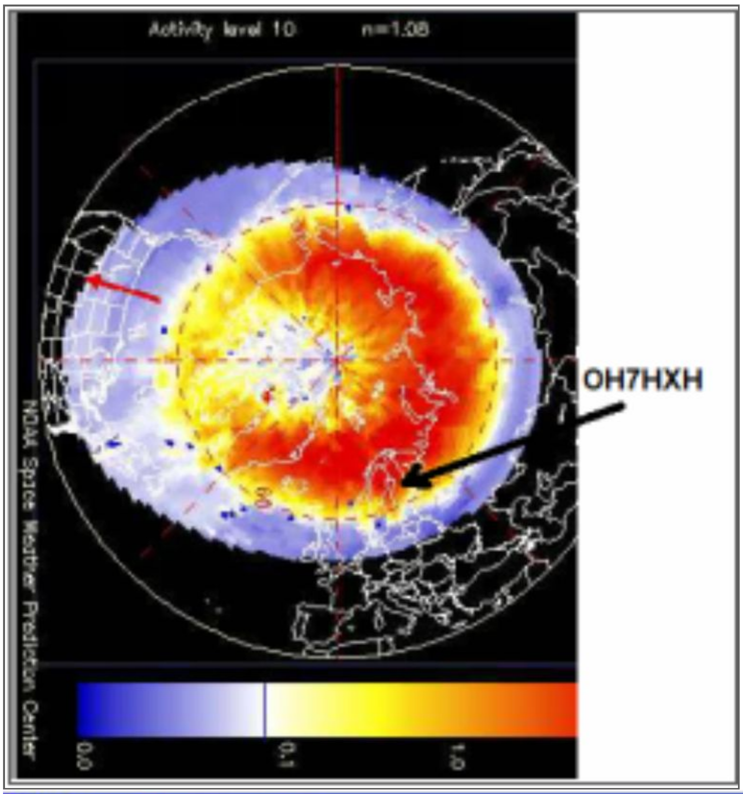
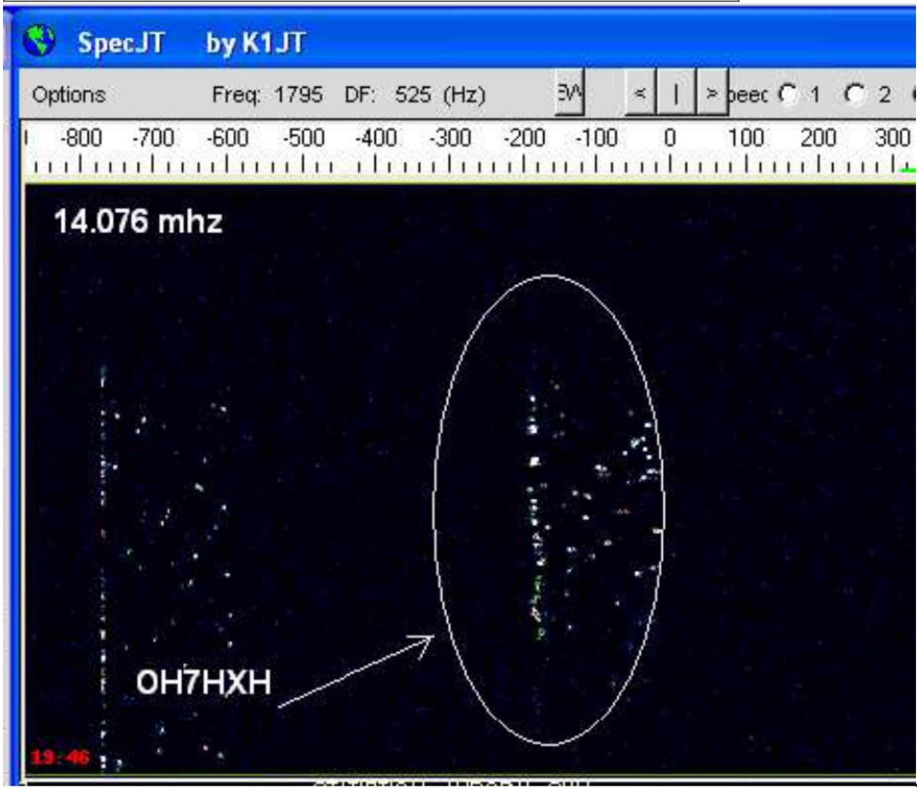

18.102 mhz
W7IXZ
spread frequency
JT65A standard signal

Fig. Flutter fading signal of W7IXZ compared with a normal JT65A signal. The ionospheric irregularities over the Aurora carry out a modulation action trough the signal spectrum. There is an interaction on the signal, as the experiment shows: there is a spread action increasing the signal bandwidth, this Doppler spreading the signal's spectrum. (Compare with JT65A standard signal in the right display).

Fig. The Aurora during the reception of W7IXZ (from NOAA statistical auroral oval) activity level of 8 in a range from 1 to 10. Image: NOAA Space Weather prediction center.





Another example significant of how the aurora can distort a radio signal is that of the April 5, 2010, at 19:47 UTC. I was listening in JT65A, on the frequency of 14,076 MHz, when I saw a completely distorted track appear on the screen of my computer, that signal appeared very distorted

compared to the other signals on the screen. The distortion was so important, that WSJT had difficulty decoding it. It was the Finnish station OH7HXH. A well-known name, as I had already connected him via EME. I immediately checked the aurora situation and I saw that the level was at the maximum, i.e., at a value of 10, with a highly disturbed geomagnetic field, with a very high Kp value of 7. I noticed that he was in the center part of Finland, completely inside the red zone, as can you have seen from the image at the bottom right.

Fig. Another example of a signal distorted by Aurora. Experiment in 20 meters with the Finnish station OH7HXH. Aurora's level was 10, which is the highest possible value. In this case the JT65A signal appears very distorted. On the left, compared to the signal of the Finnish station there is a signal (left side) coming from a station far away from the Aurora that has no distortion. In the image on the right panel, there is a real time Auroral Oval, where you can see the location of OH7HXH, inside the red zone. Image: NOAA Space Weather prediction center.

The ionosphere at high latitudes exhibits distinct characteristics due to its increased exposure to solar perturbations. The magnetic field lines converge towards the poles, extending horizontally over the magnetic equator and capturing particles emitted by the solar wind, guiding them towards the poles. This process generates minor daily secondary storms at high latitudes, resulting in the polar ionosphere being in a state of continuous agitation and strongly influenced by the intensity of solar wind and solar activity. Within the polar ionosphere, all layers, particularly the F region which is the outermost layer and thus the most exposed, experience significant dynamism linked to the evolution of these phenomena. The alignment of the force lines, which encircle concentrically around the geomagnetic poles, is horizontally oriented along the equator. This configuration shields the ionosphere at low latitudes from solar wind disturbances. The interaction between the solar wind and Earth's magnetic field gives rise to the Magnetosphere. Due to the pressure exerted by the solar wind, it takes on a characteristic comet-like shape – compressed on the illuminated side and stretching for at least 600,000 kilometers from the dark side. The charged particles of the solar wind struggle to traverse the field lines, yet they can easily glide along them. As they continue towards the tail of the Magnetosphere, they can finally precipitate within the weaker field near the poles, guided by the lines of force.

The particle precipitation comes to a halt within the ionosphere of high latitudes, leading to perturbations even in the absence of strong solar eruptions. These energetic particles, comprising high-energy electrons and protons, are captured by the force lines and accelerated within the magnetic field towards the polar regions. Upon reaching the atmosphere, they create a circular region known as the Auroral Oval. Centered around the geomagnetic pole, this oval spans approximately 3000 kilometers in diameter during periods of geomagnetic stillness. The Auroral Oval is situated between 60 and 70 degrees north and south latitudes and expands in size when the magnetosphere experiences disturbances.

Dynamical characteristics of the Polar Ionosphere

The polar ionosphere constitutes a component of Earth's magnetosphere and is subject to the influences of magnetospheric dispersion levels and the dynamics of the solar wind. Parameters of the solar wind that serve as controlling factors for the polar ionosphere encompass those associated with dynamic pressure, denoted as Psw = m * n * V (where 'm' represents the mass of protons, 'n' signifies the density of the solar wind, and 'V' denotes its velocity). Recent discoveries have highlighted that an escalation in the dynamic pressure of the solar wind induces noteworthy spatial variations at high latitudes due to particle precipitation from the magnetosphere. The day-to-day ionization level within the polar ionosphere undergoes a reduction of approximately fifty percent as the magnetopause approaches Earth. Thus, a vital correlation exists between the position of the magnetopause and the diurnal ionization level within the polar ionosphere. The composition of the ionosphere is influenced not solely by the ultraviolet radiation emitted by the sun but also by the effects originating from the solar wind and Earth's magnetic field. A substantial portion of the solar wind's energy transferred to the magnetosphere and ionosphere is localized within polar regions. Among the processes responsible for the dispersion of this energy, one notable phenomenon is the aurora.

Phenomena in the magnetopause

Energy and mass are transferred from the solar wind to the magnetosphere-ionosphere system. The primary components of the energy transfer process converge at the magnetopause, the boundary where the solar wind interacts with Earth's magnetic field. The magnetopause, especially on the sunlit side of Earth, as well as the polar regions, are highly dynamic areas. Phenomena can occur within a matter of minutes, including changes in the propagation of radio signals that can emerge and dissipate quickly due to the influence of these events. The sudden release of energy into the magnetosphere leads to what is known as a magnetospheric storm, triggering various effects, one of which is the creation of an Aurora. Nevertheless, the specific processes occurring within these explosive zones of magnetospheric storms remain unclear. For an in-depth exploration of these phenomena, encompassing characteristics such as the rapid acceleration of particles, modulation, intensified ionospheric currents, and auroral phenomena, comprehensive observations are conducted from Earth's surface. These include the usage of tools such as HF radar, specialized cameras, photometers, riometers, and magnetometers stationed in polar regions. Additionally, observations are conducted using balloons, which provide insights into electric fields and X-rays. In recent years, continuous monitoring and studies are facilitated through a network of satellites designed for polar orbits.

Magnetic storms

Magnetic storms are the largest energy dispersions occurring in the earth's magnetosphere. High-speed solar wind and interplanetary magnetic field generate large electrical forces that induce many high-energy charged particles to penetrate deeply into the inner magnetosphere. Extreme causes of this phenomenon are, for example, magnetic depression at equatorial latitudes and Aurora phenomena that also push to much lower latitudes than normal. The polar ionosphere responds globally to dispersions in the solar wind; however, the response is often different between the two polar regions (Arctic and Antarctica) that may have distinct characteristics and behaviors. Simultaneous observations in both polar regions then provide the data you compare are often different, the absorption and dispersion of energy in the magnetosphere turns out to be different between the two poles.

Structure of the polar ionosphere

Another source of ionization in the ionosphere of high latitudes is aurora, the dispersion of light caused by the spiral fall of electrons and protons hitting the atmosphere at high speeds coming from the magnetosphere with spiral motions along the magnetic field's force lines, increases the electron density in the polar ionosphere. These particles, which collide with neutral atoms in the ionosphere, as well as produce a spectacular effect of lights (Aurora visible) and supply further ionization in the atmosphere. The assorted colors of the visible aurora depend on the different gases present and their electrical status, depending on the concentration of oxygen or nitrogen atoms, the colors can vary from red to green. This added source of ionization increases during periods of high solar activity (maximum cycle one decade) and during geomagnetic storms. These phenomena occur at altitudes between 100 and 400 kilometers, although the most intense effect occurs between 100 and 150 kilometers, within E region or in the highest part of D region. Another source of ionization in the ionosphere of high latitudes is aurora, the dispersion of light caused by the spiral fall of electrons and protons hitting the atmosphere at high speeds coming from the magnetosphere with spiral motions along the magnetic field's force lines, increases the electron density in the polar ionosphere. These particles, which collide with neutral atoms in the ionosphere, as well as produce a spectacular effect of lights (Aurora visible) and supply further ionization in the atmosphere.

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Atmospheric winds and waves in the polar ionosphere, are both affected by the lower and denser atmosphere and by electrodynamic agents connected to the magnetospheric region. Particle precipitation increases electronic density as well as auroral excitation, creating strong interactions between the ionosphere, the neutral atmosphere, and the magnetosphere. The ionosphere and neutral atmosphere are bound both dynamically and chemically. At low and central latitudes on the illuminated side of the earth, for example, thermospherical neutral winds move ionospheric plasma through the lines of the geomagnetic field, creating an atmospheric dynamo that generates a whole series of ionospheric currents and the equatorial electrojet, a strong current is formed from the illuminated side towards the dark side entering the E region, along the geomagnetic equator. In polar regions, on the other hand, ions drifting inside the ionosphere, due to the electric field imposed by the magnetosphere, generate strong currents in the polar F region (polar electrojet). The ionosphere also strongly interacts with the magnetosphere, and an important function of this interaction is electrodynamic coupling performed by electric currents flowing along the lines of the geomagnetic field, which connect the ionosphere to the magnetosphere plasma. This mechanism produces an electric field, which generates the horizontal currents in the polar ionosphere responsible

for the convective flow of the ions about which we have just talked. These currents are carried by both auroral electrons that fall, following the lines of the field and ionospheric electrons flowing upwards. These significant energy flows in the upper atmosphere have profound effects on both the ionosphere and the neutral thermosphere and in addition to exciting auroral emissions, auroral precipitation of electrons increases plasma density and ionosphere conductivity. These are complex physical phenomena that interact with the dynamics of HF propagation and influence it in an important way. Great variability of energy particles in polar regions are always in a state of strong agitation, so the ionosphere is rarely well stratified and quiet. This is one of the reasons because the difficulty of the QSO with path above the poles, (the signals have to travel at least 4000 kilometers to cross the polar region and therefore are subject to a strong interaction by it), moreover this state of constant agitation causes a great variability of the MUF of F region, at our latitudes the trend of the MUF is quite regular, large changes we can find them at the grey line, in the evening and in the morning, otherwise the trend of the MUF is generally regular, vice versa at high latitudes there is a strong variability of the maximum usable frequencies that can be used , determined precisely by the same dynamic characteristics of the ionosphere whose stratification, especially in the higher and therefore more exposed regions is not uniform and undergoes continuous variations.

Geomagnetic poles

Secular variation is a regional phenomenon as well as a planetary phenomenon and is larger and more complicated in the Antarctic region. In an area of about 1000 km between South Africa and Antarctica, the centuries-old variation in the magnetic field due to the movement of the poles is 18 times greater than the planetary average. The cause of the centuries-old variation is due to convective motions occurring within the earth's liquid core. The magnetic North Pole is currently found near Ellef Ringes Island in the Canadian Arctic. The geographical position of geomagnetic poles is not stable but fluctuates over the years. There is a slow change over time, called "secular variation" of the magnetic field, observed in all its components.
The north and south magnetic poles do not have the same behavior, their variations are different both in value and direction, the north pole currently moves northeast at a speed of 12 km. per year, while the magnetic south moves northwest at a speed of about 14 km per year.

Molecular structure of Region D

The D Region holds particular significance for the analysis of absorptions affecting HF radio communications. This layer exerts the most profound influence on the attenuations experienced by wave trains traversing the ionosphere. As such, I will present data regarding the molecular structure of this region. Its importance is heightened at high latitudes, where the D Region is intricately tied to geomagnetic activity, and subsequently, to particle precipitation prompted by solar activity. Consequently, absorption is directly and predominantly influenced by these factors. This layer begins approximately 40 kilometers above the Earth's surface and extends to around 100 kilometers. Due to its proximity to the surface, the molecular density here is higher than the electron concentration, leading to an elevated frequency of collisions between neutral molecules and charged particles. The ionization density within the D Region follows a predictable pattern: it commences at sunrise, intensifies as the sun interacts with the ionosphere, reaches its zenith at local noon, starts declining in the afternoon, and abruptly dissipates after sunset. Molecularly, the composition of the atmosphere in the D Region resembles that of the troposphere. The substantial ion concentration within this region is the primary contributor to induced absorption in passing waves. This absorption results from the collisions occurring between electrons and ionized particles.

Absorption

The absorption of radio wave energy is sensitive to changes in electronic density, primarily within the D region and, to a lesser extent, in the E region of the ionosphere. Auroral absorption arises from the precipitation of energetic electrons (10 KeV) by the magnetosphere, which in turn augments the ionospheric electron density within the altitude range of approximately 70 to 120 kilometers. Particularly in the presence of ionospheric disturbances, regions of varying electronic density, spanning only a few kilometers in width, can form. These patches not only result in non-uniform absorption but also induce significant instability and signal evanescence. Sudden ionospheric storms (SIDs) elevate particle density in the lower ionospheric layers, expand their vertical reach, and depress the lower ionospheric altitude. Refraction of HF signals primarily takes place in the uppermost section of the ionosphere, the F layer, where the concentration of free electrons is higher. Frequencies below the Maximum Usable Frequency (MUF) bend towards the Earth, whereas frequencies surpassing the MUF experience minimal bending and effectively penetrate the ionosphere. Conversely, signals below the Minimum Usable Frequency (LUF) fail to penetrate the lower ionospheric layers, notably the D Region. As a radio signal traverses the D layer, it triggers oscillations in ionized atmospheric particles. Many of these ionized particles subsequently collide with neutral molecules within the D region. The density of the lower ionospheric layers directly influences the frequency of these collisions. As collision frequency increases, the energy transferred from the wave intensifies, dissipating as heat. This dynamic process defines absorption. A lower frequency results in greater signal absorption, as lower frequencies allow electrons to travel further, thereby increasing the likelihood of collisions. In summary, the interplay of electronic density, ionospheric layers, and collision dynamics intricately

shapes the absorption characteristics of radio signals within the ionosphere.

Sudden ionospheric disturbances (SID)

The solar wind exerts a potent influence on Earth's magnetic field, which responds to variations in solar wind velocity and radiation pressure. Rapid changes in solar wind characteristics can disturb the magnetic field, leading to robust currents in the ionosphere. Within the auroral zone, the intensity of ionization can become so pronounced that it absorbs all radio signals traversing through it, causing Polar Blackouts. Propagation at low latitudes is less susceptible to the adverse impacts of geomagnetic storms, although it's not entirely immune. Following high-intensity solar flares, particularly Category X Flares, which amplify solar wind (sometimes exceeding 800 km/s), HF (High Frequency) band propagation conditions suffer significantly, even at mid-latitudes. The HF propagation window refers to the frequency range between the Lowest Usable Frequency (LUF) and the Maximum Usable Frequency (MUF). Within this window, HF operators select optimal frequencies that allow their signals to penetrate the absorptive D layer and then curve through the higher ionospheric layers, notably the F region. Both the MUF and LUF curves exhibit normal and daily variations. During the afternoon, when solar radiation reaches its zenith, the D and F layers become highly ionized, causing LUF and MUF values to rise. Conversely, at night, reduced sunlight results in de-ionization, causing overall weakening of the ionospheric layers, some of which may even disappear, leading to lower LUF and MUF values. At high latitudes, due to the ionosphere's pronounced instability, these considerations acquire even greater significance. The dynamism of the layers, which are highly responsive to solar variations, leads to abrupt and less predictable fluctuations in LUF and MUF values. During a solar flare, the emission of X-rays significantly elevates D layer ionization and absorption, causing LUF to rise. This can result in a propagation blackout across the illuminated hemisphere of the Earth. Such blackouts can last from ten minutes to an hour or two, with absorption levels potentially reaching

a point where the HF propagation window is entirely closed.

Flutter Fading (distorting fading)

Signals passing through the polar zone are distinguishable due to their rapid and fluctuating fading, which is commonly referred to as scintillation. This phenomenon arises from the continuous and chaotic precipitation of energetic particles, encompassing electrons and protons with varying energy levels. These particles originate from the solar wind and become ensnared by Earth's magnetic field lines, which converge towards the poles. This process leads to the formation of irregular patches with elevated electronic density within the polar ionosphere. The polar ionosphere is inherently non-homogeneous and subject to constant turbulence. It is notably exposed to solar activity-induced changes. The numerous irregularities, characterized by gradients in ionization that perpetually shift, induce continual refractions causing signal scattering a phenomenon often termed multi-scatter. Consequently, the received signal becomes distorted and transient. Distorting fading is particularly localized, occurring only if the signal path intersects an ionospheric region harboring electronic density irregularities. Scintillation proves more severe for signals traversing close to the geomagnetic Equator. This phenomenon attains its peak intensity from local sunset until shortly after midnight, especially during periods of heightened solar activity. Auroral and polar regions experience even more pronounced scintillation, with its severity escalating during episodes of elevated geomagnetic activity.

Measurement of the Geomagnetic Field (K index)

The geomagnetic field can be measured with instruments called magnetometers. The data collected every 3 hours (3 -hour interval, K-index) from a network of magnetometers, give the situation of geomagnetic conditions and a quantitative measurement of the level of geomagnetic activity, as this value varies from 0 to 9. It indicates the maximum fluctuation of the horizontal component of the Earth's magnetic field (electromagnetic induction level expressed in nTesla) relative to a geomagnetic quiet day, measured over a three-hour time interval. A high value of the K index means greater auroral activity. The K index is necessarily linked to the specific geographical location of the observatory, so for locations where there are no observers, it is necessary to take as a reference the value of the nearest station. A weighted average of the K indices of a network of geomagnetic observatories calculates the Kp index (official planetary index) which shows the overall situation of auroral activity, and it is daily available in bulletins published on the web. For better monitoring geomagnetic activity, was introduced the A index, which is based on a larger scale than k index and which provides an average daily value of geomagnetic activity, since it is an average of all K indices of the day, the value of A index varies from 0 to 400.

Polar Cap Absorption (PCA)

Polar cap absorption, occurs after a proton flare, proton flare is the most destructive and releases an enormous number of high-energy protons, these particles that penetrate our atmosphere, are subject to the earth's magnetic field that accumulates them in the magnetic north and south poles. Here, the particles form a high-speed current, entering the ionosphere, and thanks to their high energy, they manage to penetrate even the lower layers (D region), here they collide with the molecules already present, causing more ionization that produces greater absorption of the waves in transit. Long-distance communications are therefore blocked by these events in the polar regions, signal attenuation is normally confined to high latitude areas, although in conjunction with higher flares, abnormal absorptions and therefore propagating blackouts up to 50° latitude, may occur.

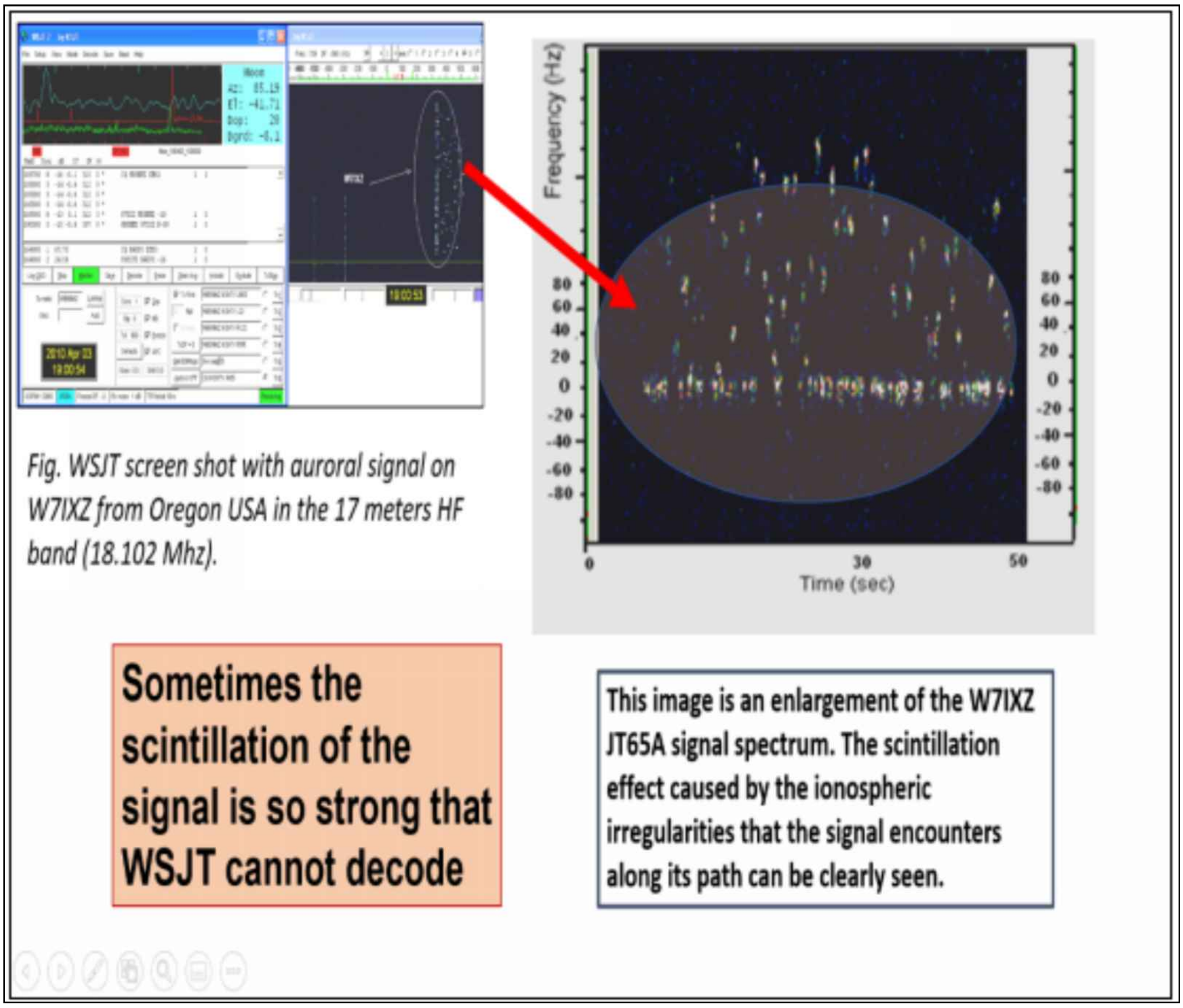
This is because abnormal absorption of D region has a long lifespan. This is due to the increase in the density of normal ionizing particles, increased by the presence of protons, whose ionization is long-lasting, such as to lengthen the recombination time.

Considerations

Practical observations confirm the theory that for an excellent quality of propagation at high latitudes, the geomagnetic field must be quiet. Communications with the American West Coast and Alaska are possible when geomagnetic activity is low. Polar path propagation depends heavily on the geomagnetic index, much more than the solar flux and the number of spots. As a rule: If the magnetic field is quiet, transpolar connections are possible even with a relatively low number of spots and low solar flux. A calm magnetic field also means low absorption of D region which is one of the causes of the propagative blackouts of the polar regions. In any case, the prediction of propagation is not an exact science. It is confirmed by the fact that I have made some QSO, even with the A index above 20 (in a range between 21 and 35, these are not high values but that indicate an active geomagnetic field) this is because it is not yet well understood how the various components that contribute to radio propagation interact with each other. We can even have different behavior in other areas of the globe.

Aurora experiment with JT65A

Dx station W7IXZ Oregon (USA)
Frequency: 18.102 MHz (JT65A digital mode)



Date: April 3rd ,2010 UTC time: 19.00

This report summarizes research on the Effects of the Aurora on Radio Wave Propagation, using the WSJT software (JT65A mode for HF communication). Experiments were conducts to detect the effect of ionospheric irregularities, such as those irregularities associated with the aurora. I analyse ionospheric fluctuations of HF radio waves and the variance of the signal amplitude and amplitude fluctuation spectra under Aurora activity. Radio-wave fluctuations are related to Aurora. During very intense solar activity, irregularities are excited in the polar ionospheric region. W7IXZ's signal from Oregon must cross the polar circle and the Aurora to get to Europe.

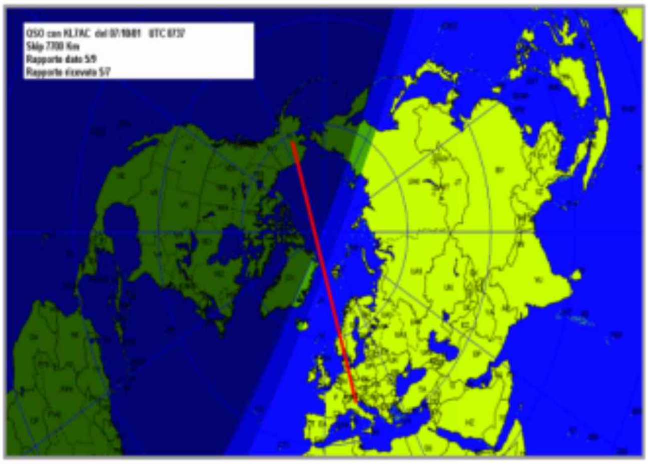
Contacts with Alaska

The ionosphere is an exceptional conductor, a fact that Nikola Tesla recognized over a century ago. Tesla's insight was based on the strong conductivity of the ionosphere, which suggested its potential for transmitting electricity across vast distances. However, this conductivity is not always active. When it is, establishing robust radio connections does not necessarily require a power plant. Conversely, when conductivity is low, even having an enormous antenna and a nuclear reactor will not help your signals reach their intended destinations. This holds true for radio enthusiasts who immediately grasp this concept. This principle applies to establishing connections with Alaska as well. The right timing is crucial. I have had numerous QSO (contacts) with stations in Alaska, primarily on the 17 meter band. The prime time is early morning, when the sun has been rising for a few hours at our location and is in the opposite phase for the correspondent in Alaska. The distance covered between Northern Italy and Alaska, 7000 km, involves transitioning from an illuminated area to a region in darkness. Given the substantial influence of the sun on ionospheric propagation, it is imperative to consider solar radiation conditions along this path. High-latitude propagation is significantly impacted by the solar wind. Its particles come to a halt in the ionosphere of these regions. Therefore, for favorable conditions, solar disturbances must be absent. Considering that the ionosphere at high latitudes is more susceptible to solar perturbations, these factors play a critical role. I have compiled an indicative map reflecting various QSOs conducted at different times of the year under similar solar illumination conditions. The terminator's position consistently aligned with this map. As previously mentioned, the most favorable, if not indispensable, conditions for contacting Alaska are during partial sunlight, just after sunrise in Italy and a few hours after sunset in Alaska. Favorable conditions entail the sun not being excessively high and the twilight belt intersecting the polar region. I have gleaned substantial data from the SUPER DARN program, which I will elaborate

on in the subsequent pages. This program provides valuable insights into the ionosphere at high latitudes.

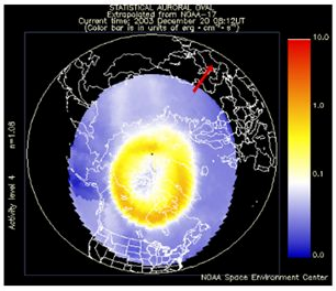
Table with some QSOs, taken as an example

STATION	DATA	UTC TIME	FREQUENCY
KL7Y	29/10/00	0805	21 mhz
NL7KF	30/06/01	0805	18 mhz
NL7Z	24/07/01	0652	18 mhz
KL7AC	07/10/01	0737	18 mhz
NL7KF	07/02/02	0710	18 mhz

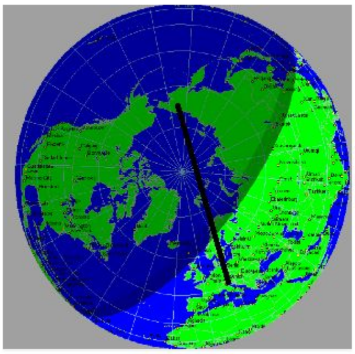


Indicative map and position of the terminator (Gray Line)
As you can see, the twilight belt passes near the North Pole.A gray line positioned in this way certainly influences the propagation at this latitude by influencing the ionospheric layers, playing in my opinion a determining role for these connections. When the path, or a large part of it, is in obscurity, there is minimal absorption and therefore there are the best possibilities for long distances.

Propagation Test with Alaska
Alaska-Italy. QSO NL7KF and IK3XTV December 20 - 2003 time: 07.55 Utc
(Frequency 18,144 Mhz)



Aurora monitor of december 20-2003 at 08.12 UTC. Aurora level = 4 During the QSO, Alaska was out of Aurora oval.



The signal was good, 5/7 without deep fading but with flutter fading (scintillation) because ionospheric irregularities on the North Pole.

Grey line position

Earth is a powerful radio transmitter

Researchers have known for three decades that the Earth is a powerful radio transmitter, but they have never been able to pinpoint where the noise is coming from. Using data from four spacecraft from the European Space Agency's Cluster mission, NASA-funded scientists have now precisely located the source of that radio noise along magnetic field lines several thousand miles above the bright regions of Earth's Northern Lights. . Although AKR is undetectable from the Earth's surface - the ionosphere blocks most of the radio waves from space at those frequencies - it is the most important and intense natural radio emission from Earth. Sounding like sporadic bursts of high-pitched whistles and squawks, AKR is emitted from Earth about one-third in the middle of each day at signal strengths of up to one billion watts. The strongest commercial radio signals on Earth are only 100,000 Watts, which means that AKR would drown most of our AM radio signals if it weren't for the ionosphere (a tenuous layer of electrified gas at the boundary between Earth's atmosphere and space). .

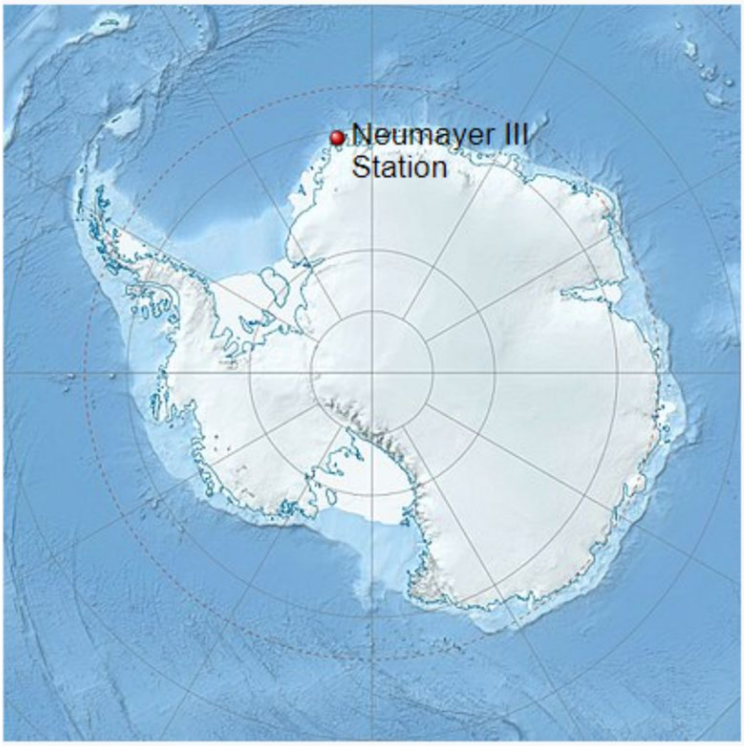
CLUSTER MISSION

The Cluster Mission is a mission developed by the European Space Agency to study the Earth's magnetosphere using four identical satellites flying in tetrahedral formation. The first four satellites were destroyed during the failed launch of Ariane 5 on June 4, 1996. The satellites were rebuilt and sent into orbit with a Soyuz launcher. The mission was extended until 2022.

The Antarctic base DP0GVN: WSPR experiments between Europe and Antarctica

DPØGVN is a station located at the German Antarctic research station "Neumayer III" at Dronning Maud Land, Antarctica. Station staff and visitors regularly activate the call identifier. The setup consists of a receiver and transmitter that independently operate in the WSPR segments of the radio amateur HF bands. Receiver: The receiver is located at the "SpuSo", the station's air chemistry laboratory. The main purpose of SpuSo is to collect c continuative data, year-round and long-term for important components in gaseous traces and particulate matter of the troposphere. This observatory is located about 1.5 km south of the main station where it finds an environment with extraordinarily clean air. This is a perfect place for a receiver because even the RF environment is surprisingly QRM-free, with 20, 30 or even above dB background noise below what we are used to in urban areas. The receiver is an SDR built around three Red Pitaya (StemLAB 125-14 with 50 dB preamplifier). The receiver is permanently all eleven WSPR band segments in 160 me 6 me load the spots on wsprnet.org. A BananaPi and RaspberryPi single-board computer take care of control tasks. The antenna configuration consists of two triangle-shaped horizontal loop antennas with Balun 1 : 4. The low bands are received by an antenna with a circumference of 171 meters, the high bands use a ring shorter than 61 meters. The antennas are mounted on short supports, about one or two meters above the ice shelf. This does not mean that the antennas are too much compared to the ground, since the ice shelf is almost invisible in HF. You can even use antennas stretched out on the ice to run QSO HF! The real ground is about 200 meters below since this is the average thickness of the ice shelf in this area. Each year the precipitation adds about one meter of snow and ice. For this, the antennas must be repositioned regularly so as not to risk having them covered by snow.

Image taken from the webcam Image of the QRZ.COM website.



Location of Neumayer II Station in Antarctica
Coordinates: 70°38′42″S 8°15′51″W

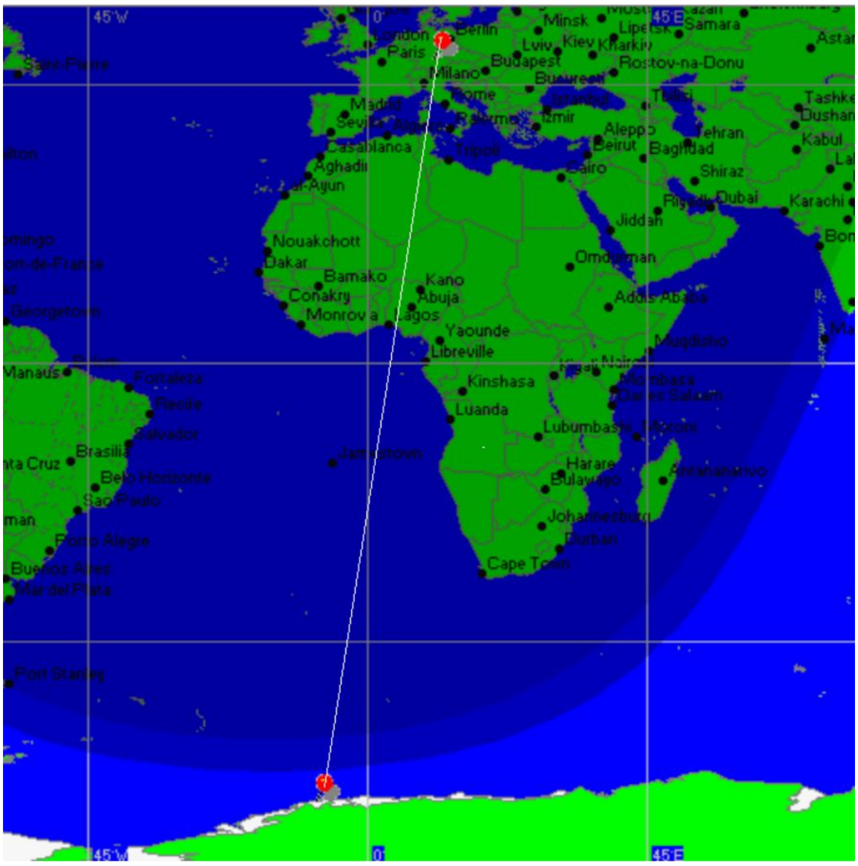


Fig. The map on the left image, shows the path with Europe with the position of the terminator in December 21 (Solstice) at 00:00 UTC. The station is more than 2,000 kilometers away from the geographic South Pole. The sun does not set at the station from 15 November to 27 January. It is polar day. In the period from 21 May to 22 July, the sun never rises above the horizon, it is the polar night.

Map created using the DX Atlas software, www.dxatlas.com.

WSPR in 40 meters between Europe and Antarctica.
To get an idea of the kind of propagation between Europe and Antarctica, I used the WSPR program. I reported in a graph the signal transmitted by DL1FX, received by DP0GVN. The chart covers 11 consecutive days, December 17-30, 2020. I have found that signal was received only during the night with the station DP0GVN, always illuminated by the sun, but with the path in total darkness, as in the map shown at the top left side. The chart shows days with longer openings and less favorable days, with very short windows. With four days without any signal (19,20,21,27 December).

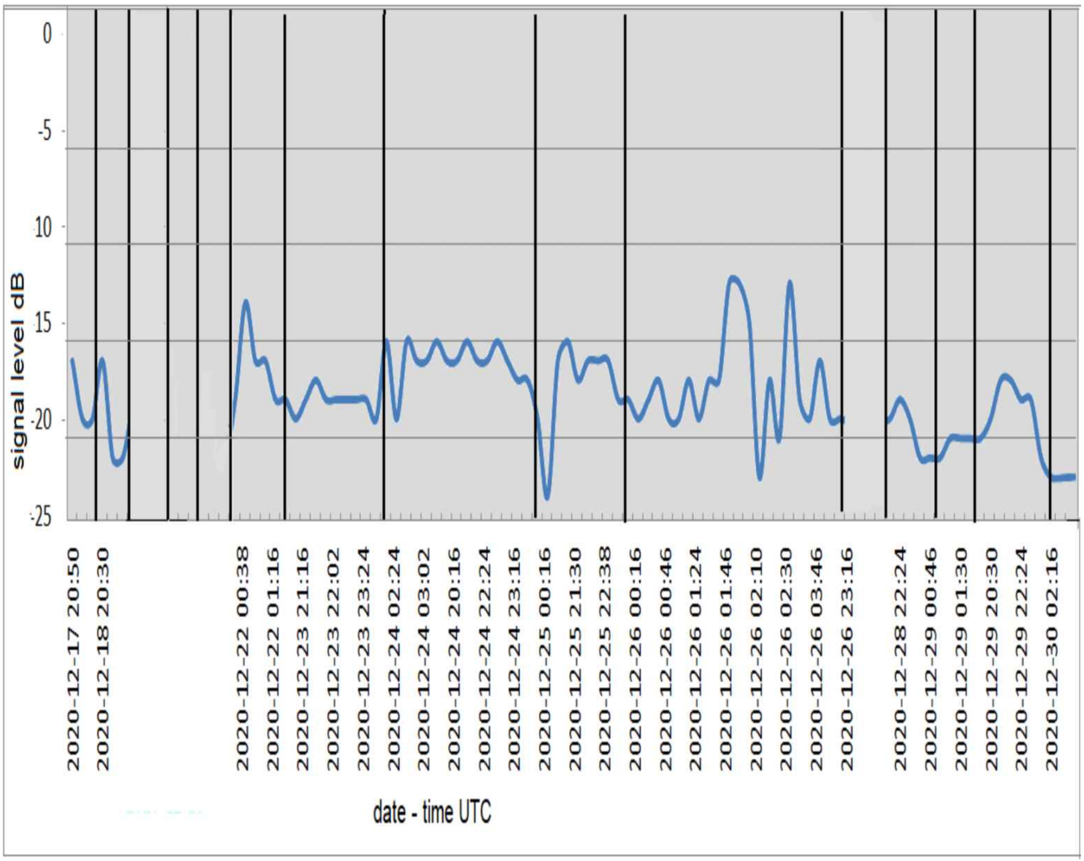
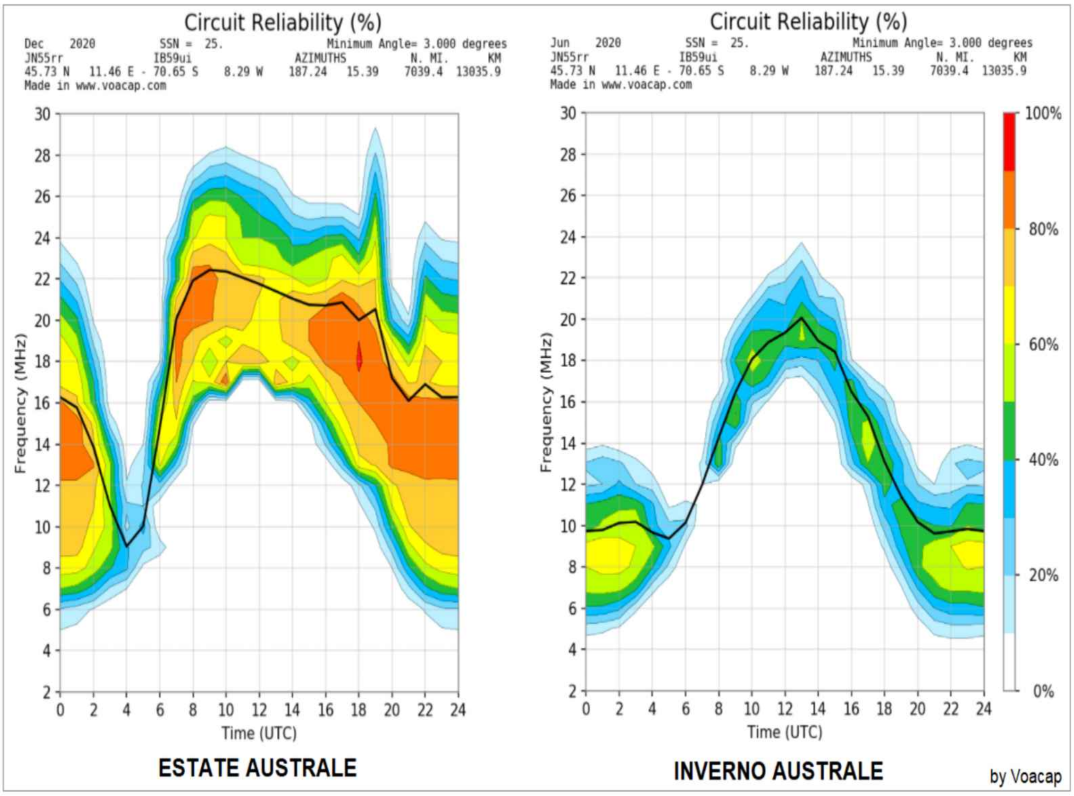


Fig. The graph of DL1FX received by DP0GVN on 40 meters. Black vertical lines delimit one day from the other. There are four days without a signal, 19,20, 21 and 27 December).



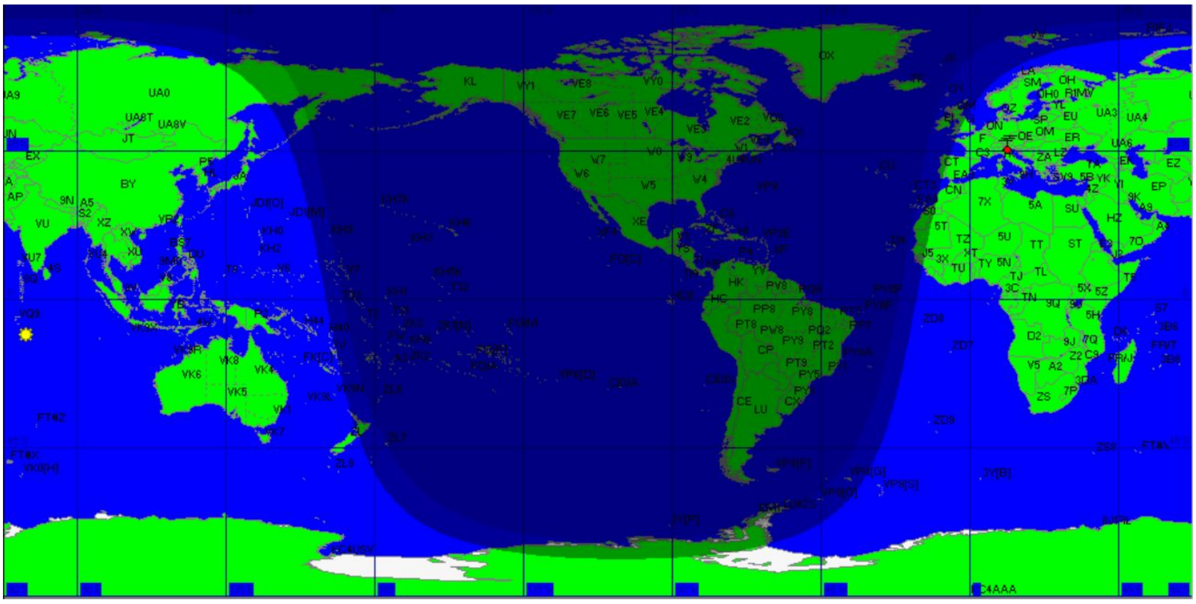
Circuit Reliability (%)
Dec 2020 SSN = 25. Minimum Angle= 3.000 degrees
JN55rr IB59ui AZIMUTHS N. MI. KM
45.73 N 11.46 E - 70.65 S 8.29 W 187.24 15.39 7039.4 13035.9
Made in www.voacap.com
Frequency (MHz)
Time (UTC)
ESTATE AUSTRALE
Circuit Reliability (%)
Jun 2020 SSN = 25. Minimum Angle= 3.000 degrees
JN55rr IB59ui AZIMUTHS N. MI. KM
45.73 N 11.46 E - 70.65 S 8.29 W 187.24 15.39 7039.4 13035.9
Made in www.voacap.com
Frequency (MHz)
Time (UTC)
INVERNO AUSTRALE
100%
80%
60%
40%
20%
0%
by Voacap

Fig. Reliability of the Connection Between Northern Italy and the DP0GVN base in Antarctica. Comparison southern Summer and Southern Winter. (Charts made with the Voacap program online).

Antipodal propagation

General

Communications with antipodes can normally occur when there is a wide ionospheric stillness, this happens with good frequency in equinox periods, on the twilight directions for the highest bands of HF, on the night paths for the low ranges. I did several QSO with New Zealand on in the same geographical area, like New Caledonia and Cook Island.



My experiences are related to the 18 Mhz band. The openings most occur early morning, so considering the 11-hour of difference, in New Zealand, it is early evening, when the archipelago is crossed by the grey line, as you can see from the planisphere below. The path length is about 18500 km. (Short path) and about 2000 km more for the "Long Way", my impression is that the communications in 17 meters take place on a twilight path, on the long path. In Italy the sun rises and the MUF begin to rise from the Southeast, on the side already in light, the twilight belt passes over eastern Siberia (zone 19) and descends towards the Pacific and New Zealand.

Map created using the DX Atlas software, www.dxatlas.com.

In the paths that follow the twilight band, long-way connections occur with discrete signals in both directions. Confirming the always valid principle, that communication is easier when one station is at sunset and the other near the sun rise.

Path

As already mentioned, communications are possible on the twilight path, along the terminator for the long path with a skip of about 20000 km. For long path, the wave across the polar regions, since along the terminator it is possible to do QSO, by pointing the antennas towards South America, then the signal descends until it laps the Antarctic region to go up the other side of the globe, towards New Zealand.

Conversely, in the opposite direction orienting the antennas to the north, you pass over the North Pole and then cross the Pacific Ocean, along the grey line, down to the New Zealand Archipelago.

The database

The statistical analysis of the QSO with New Zealand confirms that geomagnetic activity must be low and therefore in a situation of ionospheric stillness.

DATE	UTC	MHZ	CALL	SSN	S.FLUX	A index
18/03/01	910	18	ZL4HU	65	135	7
10/04/01	615	18	ZL2AAA	115	170	10
15/05/01	902	18	ZK1CG	95	145	10
29/08/01	644	18	ZL4AR	95	200	5
31/10/01	717	18	ZL2AAA	93	205	10
22/02/02	730	18	ZL1PWD	85	185	7
06/03/02	700	18	ZL4DJ	112	175	15
16/03/02	758	18	ZL2LE	95	185	3
27/08/02	630	18	ZL2LE	80	165	12
11/09/02	635	18	ZL2AAA	110	220	25
21/09/02	648	18	ZL2TW	106	160	5
01/10/02	611	18	ZL2AAA	105	140	60
19/10/02	700	18	ZL7C	155	180	11
22/10/02	630	18	ZL7C	130	170	10
23/10/02	623	18	ZL7C	115	165	10
			MEDIA	104	173	13

Although they must be interpreted with common sense, statistical data help to understand the phenomenon and show what the general trend is.

The fact of having good or bad propagation therefore depends on several factors that interact with each other, such as the irradiation of the sun and consequently, the position of the light cone on the planet (which depends by time and season), geomagnetic activity and solar flow (connected to the number of sunspots).

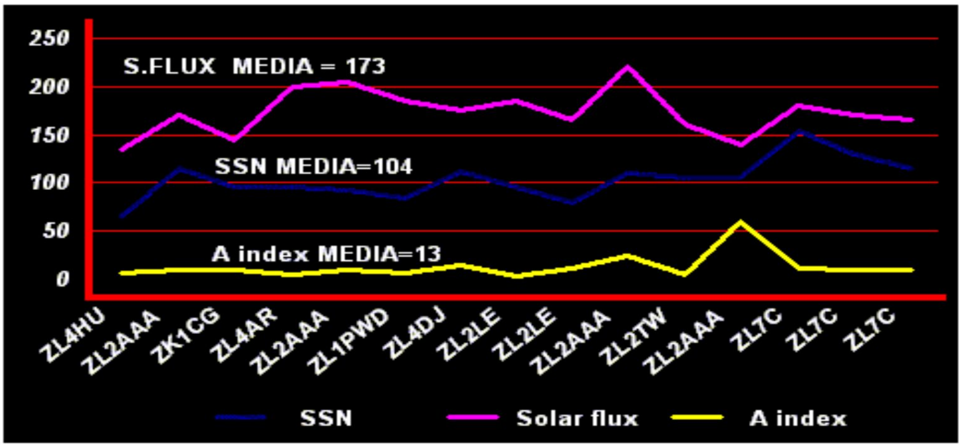


Fig. The graph shows the average solar flux, number of sunspots and geomagnetic A index for the 15 QSO with New Zealand of previous database.

Ionospheric currents

The Earth's outer magnetic field arises from the intricate interplay of movements among electrically charged particles. One of these motions involves a series of ionospheric currents that exist within the ionosphere. These specific currents, referred to as "Field Aligned Currents," follow the lines of the Earth's magnetic field due to the forces acting upon them. They emerge because of solar irradiation, which induces circulating ionospheric currents within the upper atmosphere. The accompanying figure illustrates the density of these currents in the F region. While this illustration provides a useful representation of ionospheric current movements, it is particularly significant because these currents can significantly impact long-distance connections, especially when wave patterns traverse the geomagnetic equator. In various regions, some currents exit the ionosphere, while in others, currents enter it. The density of these currents is notably higher in polar regions, where they flow outward from the polar hood but alter their course at the periphery of the auroral oval. When the Earth's magnetic field experiences disturbances, particle movements intensify, leading to heightened current strength and turbulence within the F region. For optimal reflection and refraction conditions, a uniform F region is essential. Similarly, smooth geomagnetic conditions are crucial for the antipodal path. An unsettled magnetic field disrupts layer uniformity, thereby affecting signal propagation on these paths. Consequently, signals encounter the polar zone, underscoring the importance of a calm magnetic field as a vital prerequisite for achieving Dx.

Propagation
Following the classical theory of propagation with multiple ionospheric jumps and assuming a jump distance of at least 3000 kilometers, to make a path of about 20000 Km, it would take at least 7 distinct reflections, considering the attenuations involved (geometric attenuation, attenuation on an ionospheric path, absorption for reflection, etc.) the connection should not be possible.

The signal could enter a kind of wave guide, inside the F2 night region and favored by the residual ionization of E region and therefore for widespread reflections to reach the antipodes. An advantage of the night F2 region is that it is located higher and therefore the signal undergoes less attenuation. The propagation via long path also used this phenomenon.
As already mentioned, to allow the signals to enter the wave guide, ionospheric discontinuities are necessary, discontinuities that are found for example along the grey line, due to the different radiation pressure that you have on the terminator, in fact the correspondent is on the grey line at sunset, while in Italy the sun has already arisen and the progressive ionization of the low layers begins. This is where we can find those discontinuities capable of bending wave trains within F region.

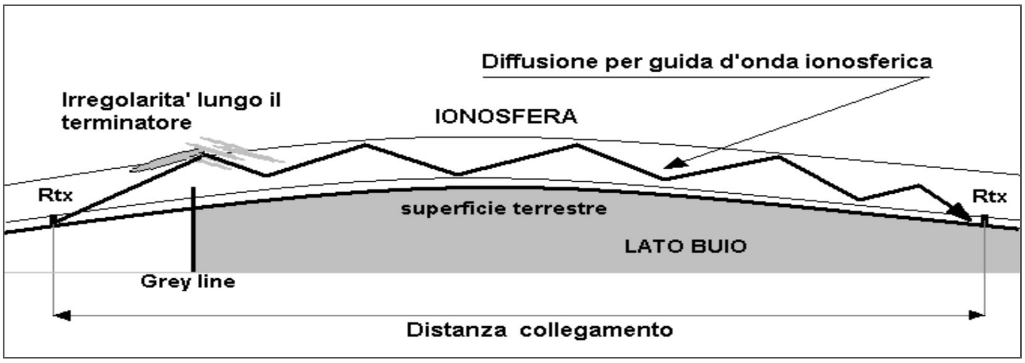
Propagation for ionospheric wave guides

Below is what Marino Miceli, I4sn, wrote many years ago, on "Radio Rivista" 10/1994:
"Long-distance propagation may occur a little differently than current literature teaches. Conventionally accepted theory states that at most 2200 kilometers from the station, a radiated wave train with small angles encounters in F region, an ionization density such that the curvature, as a result of the more accentuated refraction, sends the signal back to the ground. The ground return signal laps the ground to a maximum (theoretical) of 4200 kilometers from the station. Here the waves are sent back to the ionosphere and, for subsequent jumps, cover not only the 20000 kilometers of the hemisphere, but in a mild absorption condition, as along the grey line, they can recycle (in 28 or 50 MHz), in order to cover routes of 120000 kilometers and still be audible. This was stated earlier by VE2AEJ, nor is there any valid reason to doubt this OM (which is part of the Geomagnetic Observatory of Canada). The experiences of QRPp stations operating with 100 mW. applied to a dipole show that this conventional theory does not hold. In fact, even assigning to each reflection on the ground only 3 dB of attenuation (which is the minimum expected and only on the sea) the accounts do not return. To reconcile OM's many relationships with theory, years ago I advanced on the pages of RR, a hypothesis that Mackenzie now seems to confirm in a CCIR report. Mackenzie and I would be about the same idea: the wave front, a few miles from antenna has a very large surface, the subsequent ionospheric curvatures mean that much of the energy returning from the ionosphere descends to earth, not proceeding according to a line (as the theory would have it) but already curved and oriented to go up towards F layer. Of course, a percentage of this signal, which is gradually expanding, reaches the ground at 3000 or 4000 kilometers away and allows reception in every location whose distance is "beyond the area of silence" but it would only be a fringe of the scattered wave front.

Wave guides

The impression is that wave guides are forming, capable of transporting signals at very great distances and with little attenuation. The openings that often occur in the morning, to New Zealand or to the islands of the Pacific Ocean, by the long path, further reinforce this theory.
It is possible that there are focus phenomena along the way, like occurs for the visible light emissions, able to focus the electromagnetic wave and therefore greatly lower the attenuations.

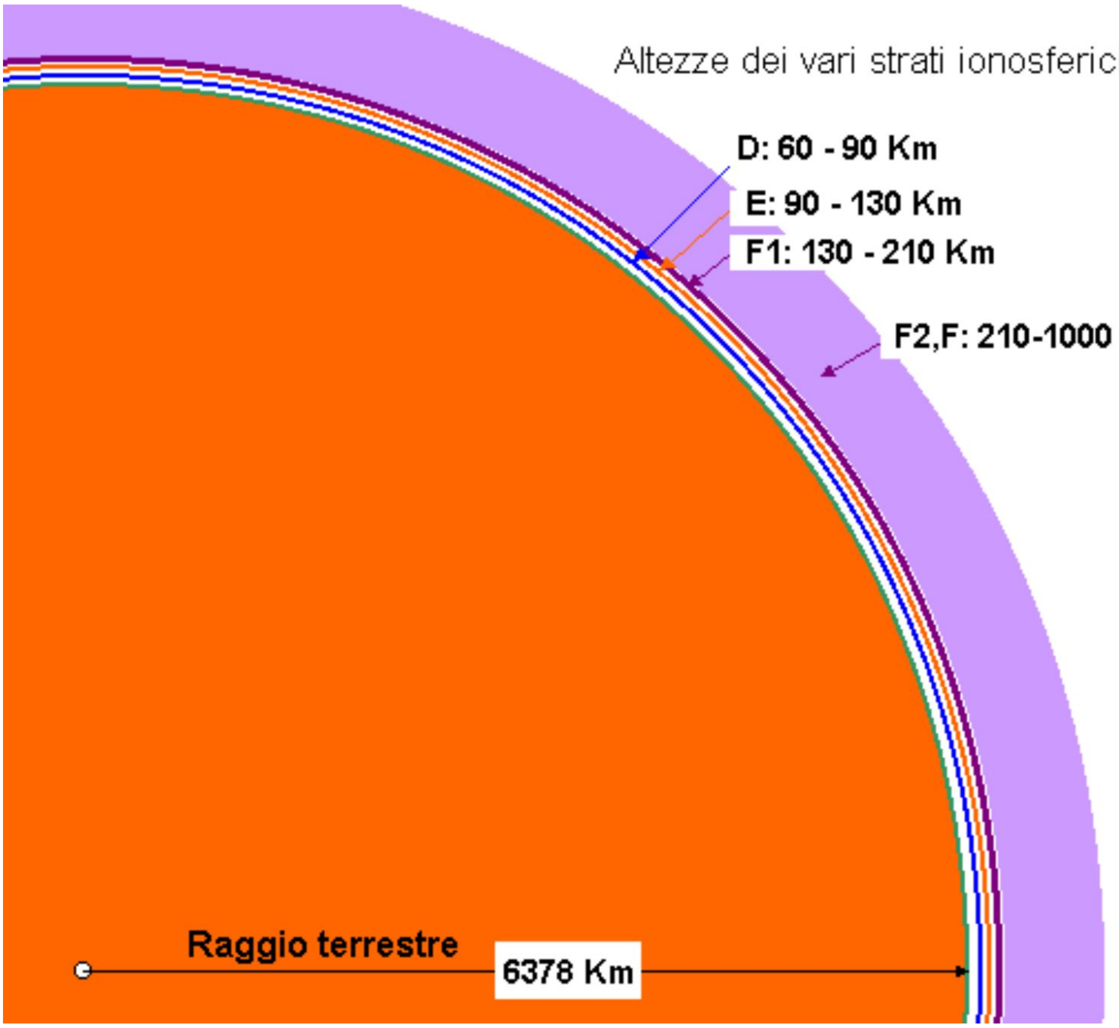
Wave guides are governed by the level of geomagnetic activity and the degree of ionization of the ionospheric layers; however, the wave guide may form between the ionospheric layer reflecting at the top and the Earth's surface at the bottom.



In the provided figure, I have reconstructed the dynamics of the signal path. This reconstruction is based on an example that traverses both the illuminated and the shadowed sides of the Earth. In this endeavor, I aimed to adhere to Earth's geometric attributes and the hypothetical altitude of the reflective ionospheric layer, which I estimated to be around 250 km. The illustration was developed with the Earth's radius of approximately 6300 kilometers in mind. Accurate depictions of Earth's dimensions and ionospheric layers are crucial for elucidating the hypothesis of Dx propagation through ionospheric waveguides. The viability of favorable paths hinges on a complex interplay of multiple interacting variables.

Several critical conditions warrant examination, based on my observations:

- Low Geomagnetic Activity: A low value of geomagnetic activity, as indicated by very low K indices, is essential.
- Minimal D Region Absorption: The position of the terminator and the overall solar radiation cone are of utmost significance. Solar irradiation levels dictate the state of the ionospheric layers. Solar indices that have the potential to ionize the atmosphere and activate potential waveguides become crucial factors.



Consequently, propagation becomes feasible only in specific directions when these conditions are met. Moreover, these parameters adopt increasingly stringent values as connection distances and ionospheric paths extend. Within these paths, phenomena analogous to the focusing of electromagnetic waves, reminiscent of how optical lenses focus light waves, may emerge.

Whispering gallery

In addition to the information mentioned earlier, another phenomenon that could come into play is analogous to the concept of a "Whispering Gallery," commonly observed in acoustics. Under the influence of both solar radiation and irregularities within Earth's magnetic field, it is possible for curved ionospheric regions to emerge. These regions might appear near the magnetic equator, forming what is known as the "equatorial anomaly." In these cases, the ionosphere curves upward, resembling a dome-like structure. In other scenarios, such as along the grey line or in areas with geomagnetic irregularities, discontinuities could arise, potentially preventing significant attenuation over very long paths. Within a curved ionospheric region, a phenomenon akin to the "Whispering Gallery" effect might apply. This concept, previously discussed by Marino Miceli in “Radio Rivista,” involves acoustic waves touching the curved surface of a vault (dome), undergoing slight jumps along the surface before arriving at the opposite side with minimal attenuation, a process that leverages the Huygens principle. Analogously, with electromagnetic waves, it is conceivable that wave beams entering a curved ionospheric layer could persist with minimal losses across thousands of kilometers, only to be deflected towards the ground by the previously mentioned discontinuities, like those occurring at the terminator, near the geomagnetic equator, or due to ionospheric turbulence. In the context of antipodal connections, where the signal path can be thought of as ellipsoidal, the Whispering Gallery effect might prove significant. This effect could negate the impact of geometric attenuation, thereby enabling even exceedingly weak signals to remain discernible over considerable distances.

Huygens principle

The Huygens principle is expressed in the following form: Any point on a wave front can be considered as a point source of waves propagating in the same direction as the front itself.

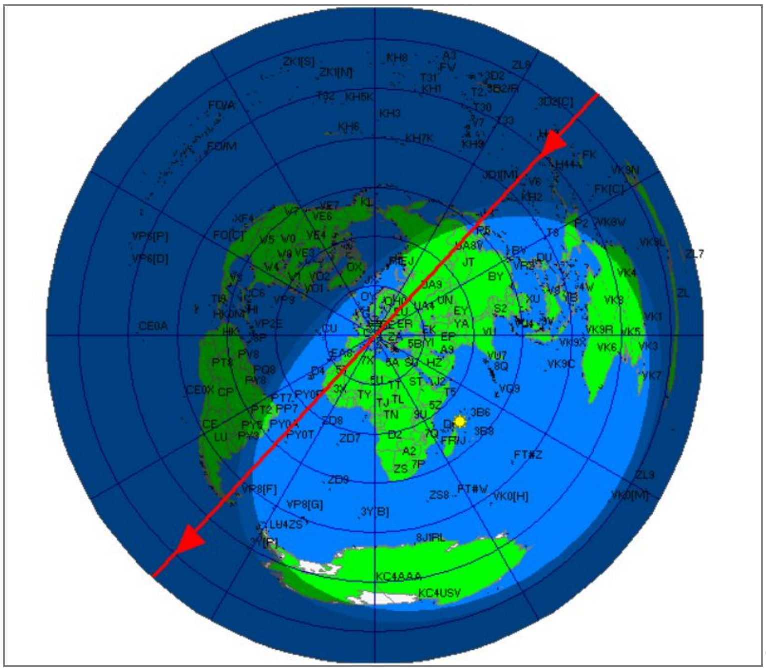
Long path

The dynamics of long path propagation are like the analysis made so far for the antipodal connections, so I report below some considerations on an interesting QSO that I made on 23/02/2003 at 08.45 UTC, on 18 MHz frequency.

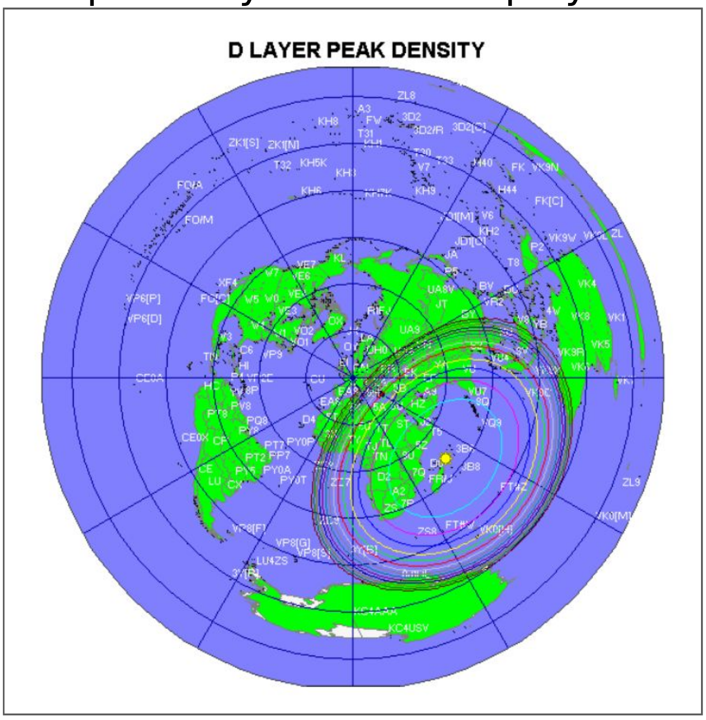
Some QSO experiences

On Sunday, February 23, 2003, I heard the station OK2ZW from the Czech Republic operating on 17 meters, establishing connections with Japanese stations. To my surprise, the Japanese stations received OK2ZW's signal better via the long path. Interestingly, I also received OK2ZW's signal via the long path, despite my antenna being directed in the opposite direction. The signal transmitted by OK2ZW reached my location via a long path covering approximately 39456 km, effectively circumnavigating the Earth's circumference. This signal exhibited the typical fading distortions often observed in signals passing through the geomagnetic equator. Additionally, a strong echo effect was noticeable due to the signal's traversal of multiple paths, potentially looping around the Earth multiple times. Throughout our communication, we conducted tests by aligning our antennas for the short path initially and then assessing propagation for the long path. The short skip towards OK2ZW (548 km) experienced weak or closed reception, and signals from other stations within a similar radius distance never attained significant strength, rarely exceeding S 2-3. In contrast, despite the long path's distance exceeding 39456 km, OK2ZW's signal arrived with an impressive strength of S8, markedly stronger than the S2 signal observed on the short path. OK2ZW employed a Yaesu FT1000 MP transceiver, an 8-element log periodic antenna spanning 14 - 30 MHz, and utilized about 1 KW power. On my end, I utilized a Kenwood TS870 transceiver, a 2-element Yagi antenna designed for 18 MHz, and operated with 200 W power. This remarkable long-path propagation facilitated a unique and exceptional contact between our respective stations.

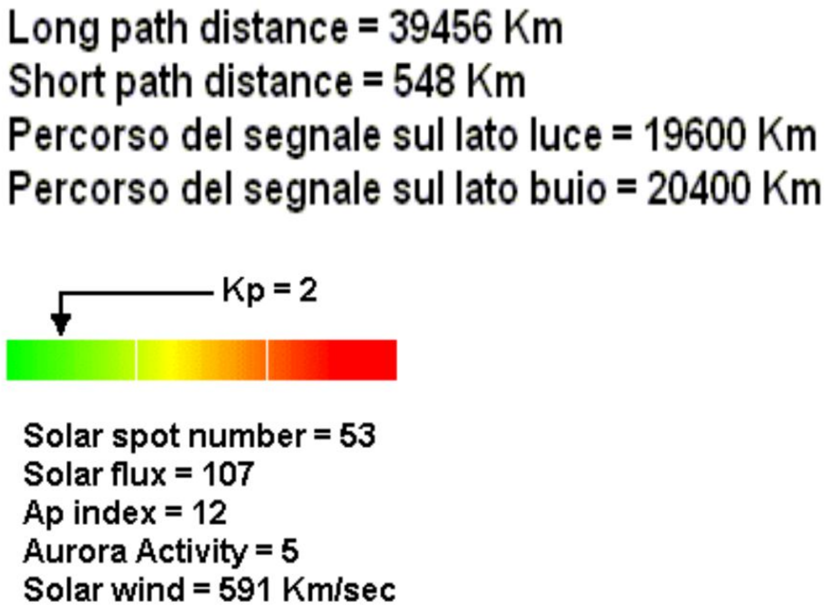
Considerations



Once again, we have confirmation of good propagation (in this exceptional case) when geomagnetic activity is low, in fact the Kp index was equal to 2, with several spots (SSN=53) and the solar flux=107), low. It is a confirmation that propagation is not linked to these two values but that a whole series of complex ways come into play.



Map created using the DX Atlas software, www.dxatlas.com.

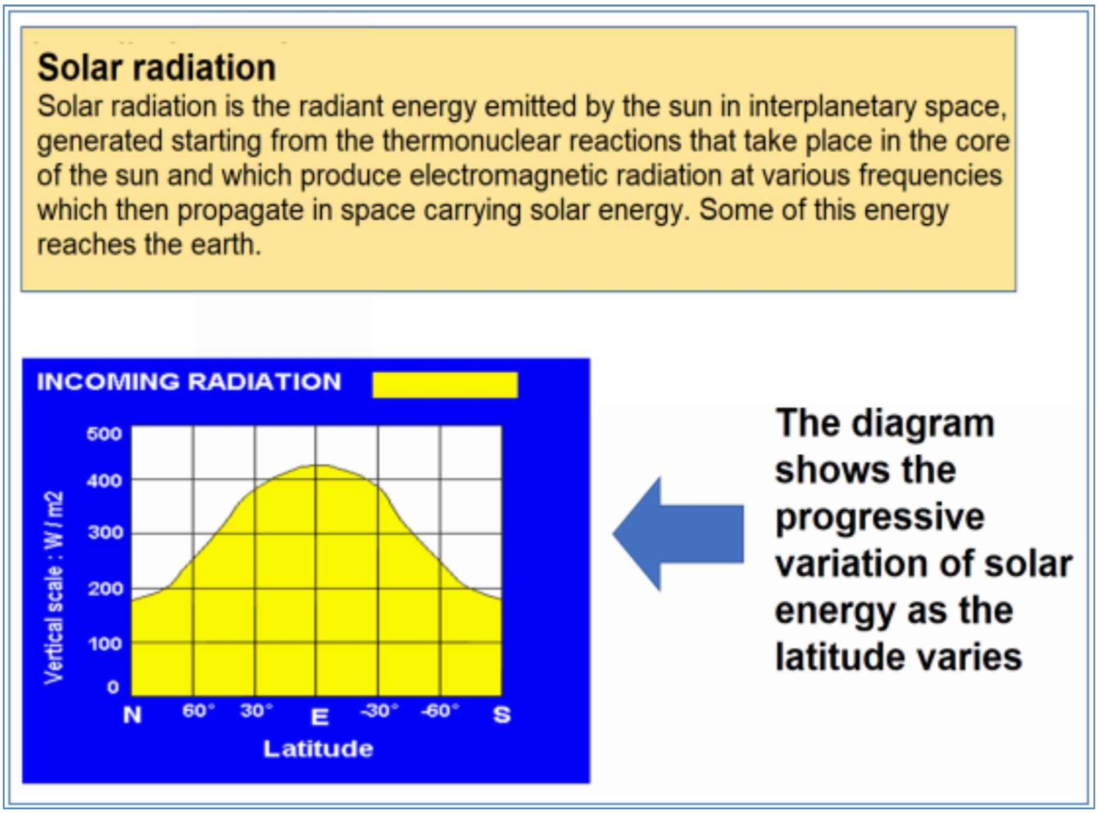


In the azimuthal map above, I have plotted the path of the signals, which is shown as a bold line that passes over the top of the cone of sunlight on Earth. The total path length was about half on the shadow side and the other half on the illuminated side. The D layer's attenuation was slight on the sunlight side, as indicated in the right panel (D layer peak density), where I included concentric lines representing the maximum absorption of the attenuating D region. The path of the wave trains was external to the area of maximum absorption, which is associated with the region of greatest irradiation.

Upon analyzing the path's morphology over approximately 40,000 km, the signal spread occurred at about 11,500 km above the Earth's crust and for the remaining 28,500 km over the ocean and the ionosphere. It is known that reflection on water introduces much lower absorption than reflection on the Earth's soil. This observation may be relevant for connections via long path in general, considering that ocean masses cover about 70% of the Earth's surface. For completeness, I also included the extension of the Aurora radio (Activity level = 5), even though the signal path does not intersect the auroral zones. The considerations made earlier about phenomena such as "Whispering Gallery" or the focus gain by the signal along the path could be valid and may contribute to the amplification of electromagnetic waves in certain cases.

Solar radiation

The systematic observation of HF propagation has convinced me that the intensity of solar radiation plays a primary role in the dynamic of signals. The opening and closing of our HF bands are strictly dependent by the position of the sun and the amount of energy that arrives on earth. As can easily be deduced, the different propagation characteristics depending on latitude, depend on different solar radiation on the ionosphere, which gradually decreases from the equator to the poles, following the course of the seasons. The most noticeable and direct effect of the sun's radiation occurs in D layer, where the density of the layer, and consequently its attenuating power, is directly proportional to the amount of energy that arrives on earth. D region forms slowly as the sun rises and degrades rapidly after dark.



Earth's magnetic field

Introduction

The Earth consists of:

- Solid crust
- Semi-solid mantle
- Liquid iron outside the nucleus
- Solid iron inside the core

The earth's magnetic field comes from the combination of three sources:

- 97-99% Main magnetic field, generated by electric currents in the liquid iron layer outside the core.
- 1-2% Surface magnetic field resulting from the residual magnetization of rocks in the crust.
- 1-2% External magnetic field, generated by ionized particles in the Ionosphere.

The main magnetic field is like a dipole and varies in intensity from about 30,000 nT near the equator to about 60,000 nT at the poles. The centuries-old variation in the magnetic field implies a variation of about 1% per year, while on average every 500,000 years, magnetic poles reverse.
The outer magnetic field varies over a time scale of seconds to days, due to solar interaction. These fields are the result of a system of ionospheric currents and vary in value from fractions of nT up to thousands of nT. Lines of strength of the geomagnetic field of the earth and difference between geographic poles and magnetic poles (declination). The north and south magnetic poles do not have the same behavior, their variations are different both in value and direction, the north pole currently moves northeast at a speed of 12 km. per year, while the magnetic south moves northwest at a speed of about 14 km per year.

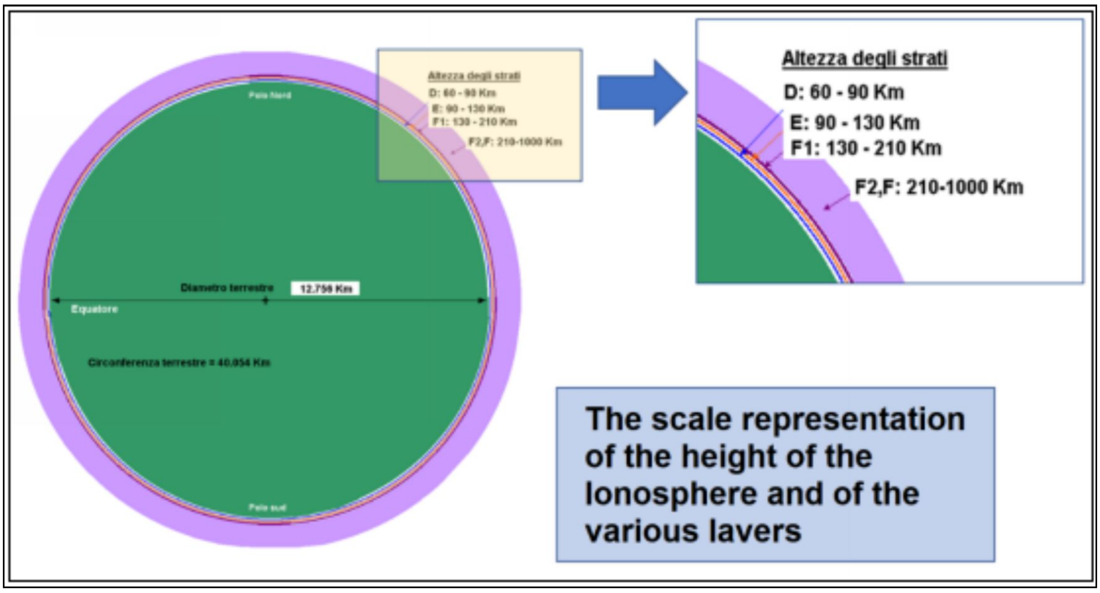
Earth's magnetic field
When measuring the Earth's magnetic field at a certain point on the surface of our planet, it supplies a value that is the result of overlapping contributions from different origins. These contributions can be considered separately and each of them corresponds to a different field:

1) Main field, generated in the fluid core by the geo dynamo mechanism.
2) Crustal field, generated by magnetized rocks of the Earth's crust.
3) External field, generated by electric currents flowing into the ionosphere and magnetosphere because of the

interaction between the solar wind and the geomagnetic field.

Electromagnetic induction field, generated by currents induced in the crust and

Earth's magnetism is a natural physical phenomenon on planet Earth, like the magnetic field generated by a magnetic dipole with magnetic poles not coinciding with geographical and non-static poles, and with an axis tilted 11.30°, respect to the Earth's axis of rotation. The intensity of the geomagnetic field on the Earth's surface varies from 25 to 65 microTesla (or from 0.25 to 0.65 gauss). Other celestial bodies, such as the Sun or Jupiter, also generate their own magnetic field. The hypotheses about the origins of this field are numerous, but today the theories are oriented towards a model like that of a self-exciting dynamo. The main field stands for 99% of the entire magnetic field observed on the surface. His simple morphological study shows that the field is 95% analogous to that generated by a dipole located in the center of the Earth whose axis is tilted, with respect to the Earth's axis of rotation, by about 11.5°. The International Geomagnetic Reference Field (IGRF) is a global model of the geomagnetic field and is intended to represent the contribution of the main field alone. The residual part at the IGRF observed on the surface represented the contribution of anomalies of the geomagnetic field, i.e., deviations from the theoretical trend of the main field. Going into more detail, anomalies can be divided schematically into regional anomalies, with extensions of thousands of kilometers, and local anomalies, with inferior extensions.



The International Geomagnetic Reference Field (IGRF) is a global model of the geomagnetic field and is intended to represent the contribution of the main field alone. The residual part at the IGRF observed on the surface is the contribution of anomalies in the geomagnetic field, i.e., deviations from the theoretical trend of the main field. The geometry of Earth's geomagnetic field has the lines of force entering the Earth in the northern hemisphere and entering the southern hemisphere; thus, the north polarity free extreme (positive) of a magnetic needle will tend to settle vertically with its North down in the presence of magnetic pole of South polarity (negative). It is, however, traditional to call the North Earth magnetic pole simply what is in the Northern Hemisphere and southern magnetic pole what is in the Southern Hemisphere, in accordance with the corresponding geographic poles.

Crustal geophysics

The study of magnetic anomalies, i.e., irregularities in the Earth's magnetic field of crustal origin, is a geophysical method of enormous use for investigations into the deep structure of a given area. A map of magnetic anomalies is the result of the sum of the magnetic fields associated with the magnetization of the sources present in the Earth's crust. Geophysical techniques, such as ground magnetometry or aero magnetism, associated with anomaly analysis, allow information to be obtained on the underground distribution of magnetizing bodies. The magnetic method as a means of exploration has its origins from the studies of anomalies detected at sea, linked to the expansion of the ocean floor. Today this method is widely used both on a large scale for regional studies and in high-resolution investigations for mining, archaeological, tectonic and volcanic purposes.

The Earth's magnetic field is expected to grow steadily from 0.28 oersted at the Equator to 0.71 oersted at magnetic poles. In fact, between these two extreme values the magnetic field is distributed in a way that is not always predictable precisely because of the presence of anomalies of origin that are still little known and because of the oscillations mentioned in the first paragraph. For this reason, the study of magnetic anomalies refers to a regional normal magnetic field, i.e., well defined for an area of limited amplitude. The most intense and localized anomalies are those caused by deposits of ferromagnetic material, intrusive and effusive rocks covered with sedimentary deposits, by the crystalline base. To assess the intensity of these anomalies, periodic fluctuations must be subtracted from the measurement on the ground, in addition to the normal regional field. In addition, the amplitude depends on the stage of the cycle of sunspots. The daytime variation is generated by a system consisting of two large vortexes of electric current in the ionosphere in the Sunlit hemisphere, one in each hemisphere traveled in the opposite direction (counterclockwise in the Northern Hemisphere). The centers of these vortexes are located at latitudes of about 40° and close to the meridian of the Sun. These local magnetic fields, in some respects, are the analogue of terrestrial magnetic anomalies. At 400 km, the largest magnetic anomalies on Earth (detected by satellites) can cause a change in the intensity of the ± 10 nT (nano tesla). By comparison, the geomagnetic field on the magnetic equator has an intensity of 3·104 nT. At the same altitude, the most intense Martian anomaly (present in the Sirenum land region between 120°-210° W and 30°-85° S) has a variation of ± 200 nT: a value 20 times higher than that of the Earth. This magnetic field is intense enough to divert the solar wind and give rise to a magnetosphere.

Geomagnetic abnormalities

There are studies which try to explain how the distribution of sporadic E is not entirely random but there are favorable areas, where there, seems to be a greater concentration of the phenomenon.
One of the theories, developed by some radio amateurs in the past, is attributed to geomagnetic anomalies of the Earth's crust, able to thicken and favor the formation of Es curtains in certain geographical areas. Such a hypothesis would be very well coupled with the meteoric origin hypothesis of Sporadic E.
The metal dust could easily be concentrated in areas where these anomalies exist, contributing fundamentally to the formation of clouds. There are some areas on earth where significant anomalies of the geomagnetic field are located and are a cause of aggregation of the meteoric dust.

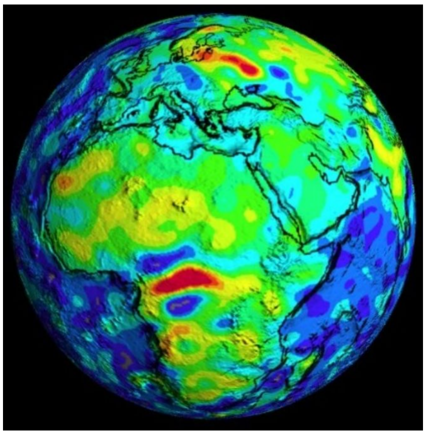


Fig. Darker spots highlight and Bangui's magnetic anomaly in the Central African Republic and Kursk's magnetic anomaly in western Russia.
Image credits: Wikipedia Public Domain.

Agents that contribute to the formation of the earth's geomagnetic field:

Main field generated in the fluid nucleus by the geodynamic mechanism).
Crustal field generated by magnetized rocks of the Earth's crust.
External field, generated by electric currents flowing into the ionosphere and magnetosphere because of the interaction between the solar wind and the geomagnetic field
Electromagnetic induction field generated by currents induced in the crust and mantle by the outer field varying over time.

Note: Some chapter information by Wikipedia.

Background noise

Atmospheric noise

HF low bands have higher atmospheric noise than higher frequency bands. At 7 MHz, atmospheric noise is always high, with values higher at night than during the day, due to the greater attenuation suffered by daytime ionospheric propagation caused by region D. (Noise is always an electromagnetic radiation that propagates within the ionosphere responds to the same laws and undergoes the same attenuation as the actual signals). The effect of atmospheric disturbances completely ceases for frequencies above 30 MHz, both because its energy contribution is now insignificant and because ionospheric reflection becomes unlikely at these frequencies. I report a graph where, as a function of frequency, disturbances are depicted, neglecting galactic noise, which turns out to be almost constant for the entire spectrum of H. Atmospheric noise decreases progressively as already mentioned with frequency, above 22 MHz becomes negligible. The atmospheric disturbance is due to temporal electrical discharges and is therefore subject to wide variations over time depending on seasonal and daily climatic conditions. The 40-meter band is quieter in winter precisely because the probability of thunderstorms in our latitudes is lower. Each discharge caused by a thunderstorm originates RF pulses, with decreasing spectral density with frequency, propagating in all directions (the average number of thunderstorms occurring simultaneously on earth is about 1800, with an average number of 100 electric discharges/sec.). As a result, their effects are assessed up to long distances since propagation can occur ionospherically. A local effect is distinguished, caused by local weather conditions, and a distant effect. The first is a sequence of very intense impulses but spaced out over time, while the latter loses its markedly impulsive character due to the random overlap of the effects due to many distant discharges.

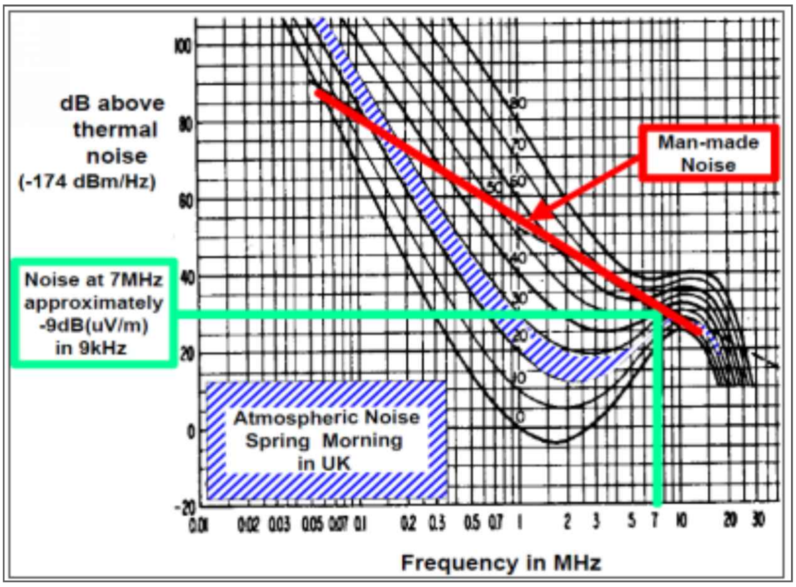


Fig. atmospheric noise relationship. The standard has tables and maps that determine the noise figure at 1 MHz according to the season and the time of day. This graph converts that noise figure to other frequencies. Notice that the plotted lines are spaced in 10 dB increments at 1 MHz.Credits: Amount of atmospheric noise for LF, MF, and HF spectrum according CCIR322 - with overlaid lines

added by G3JWI for published presentation on behalf of RSGB. Image by Wikipedia public domain.

W8WWV, Greg Ordy -Summer Summary 2003 Noise Monitoring

Thanks to Greg Ordy, because he gave me his permission to publish these interesting studies of his research about noise in the bands of 40-80 and 160 meters. They are significant, because they allow to give an idea of the background noise, in the low bands of the HF.

His first round of monitoring took place in July, of 2003, which is his local summer. The 160 meters, 80 meters, and 40 meters results are presented on these pages. He monitored each band on successive weeks. Even though sunrise and sunset times are changing, it is interesting to overlay the three different bands on one graph.

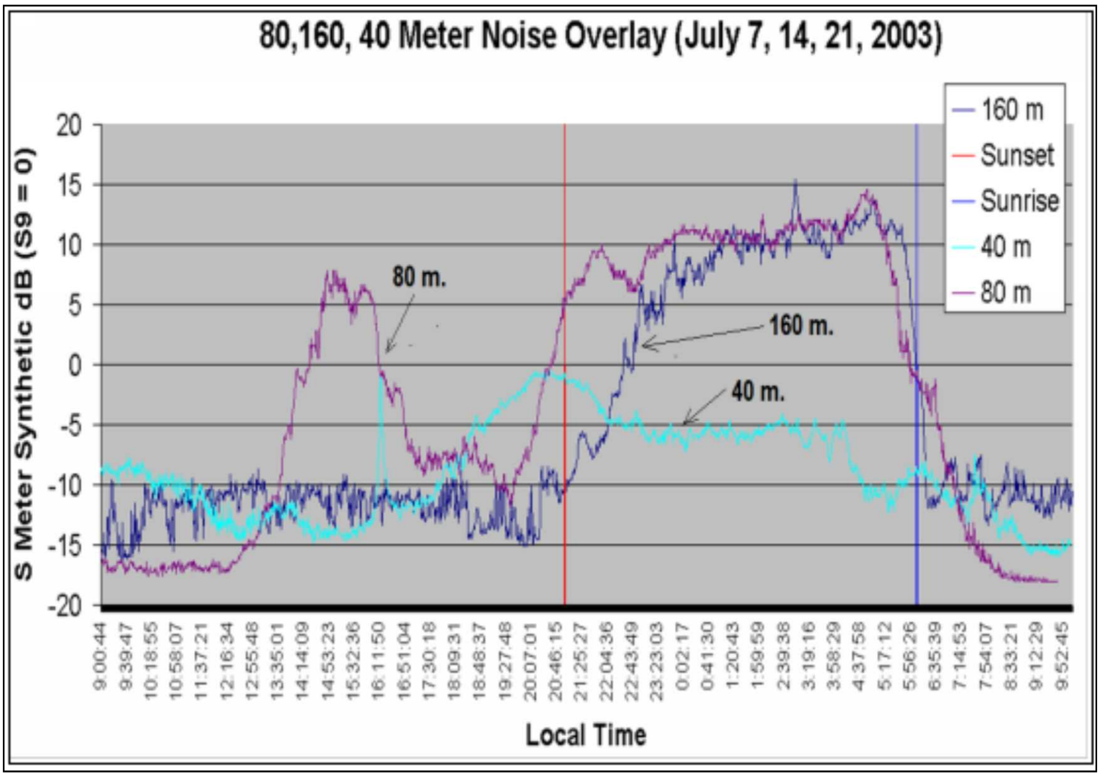


Fig. The noise level of the 160-meters, 80 meters, and 40 meter band on a single graph.
Credits: Greg Ordy, W8WWV.

Measurements by W8WWV

We are ready for the measurements. In general, the radio was set up to some unoccupied frequency near a given amateur band and began recording the S Meter. He tried to record data for several days. Unless otherwise modified by a given measurement page, the conditions are as follows:

The radio used is an ICOM 756PRO and it supports remote reading of the S Meter.

Preamp set to maximum. The idea here is to discourage the meter from bottoming out at S0 when the band is quiet during the day. In normal operation, the use of preamps on the lower bands is seldom necessary. The receiver is set to the CW mode, with a 350 Hz filter width. The receiver AGC is set to the factory mid position, which is 0.5 seconds. Since the goal was to measure background noise, He need to pick frequencies which do not have signals. This is impossible to guarantee within the amateur bands, so he normally selects a frequency right below the bottom of the amateur band. Data are sampled at an interval of 1 minute. Since S Meter Lite samples, the S Meter at a rate of 20 times per second, each sample in the file consists of the average of (60 X 20) or 1200 S Meter readings. The data was recorded with the software created by Greg: “S Meter Lite program.” This program reads the radio receiver's S Meter through the computer, and in this application, saves the readings in a data file.

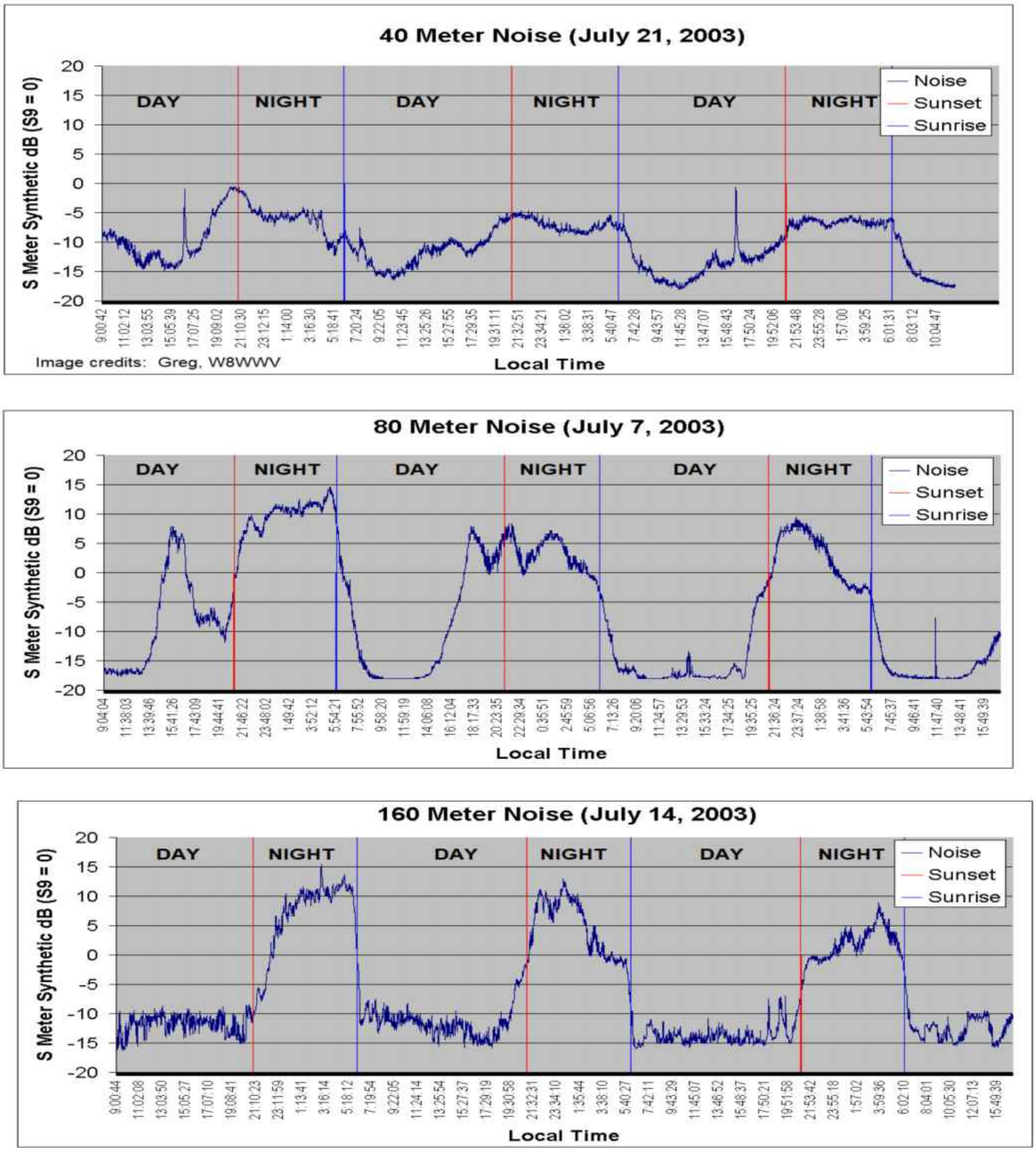


Fig. Background noise monitoring for a few consecutive days on 40-80 and 160 meters. Credits: W8WWV.

Considerations by Greg W8WWV

The general sense I got from looking at this data, and the data on the individual band pages, was that 80 meters and 160 meters noise tends to move between their day and night values in rapid transitions. On 160 meters, the transition seems closely tied to actual sunrise and sunset times. On 80 meters, at least during this monitoring period, the noise level would sometimes rise in the middle of the day, which is a little unexpected. 40 meters did show a difference between day and night noise levels, but the transitions took much more time. It seemed as if the 160 meter band was like a square wave, moving quickly between day and night noise levels. As the frequency went up, the shape of the transition went from square wave to more like a sine wave. It took many hours to move between the day and night noise levels. The noise level was also lower on 40 meters, averaging 10 to 15 dB lower than on 160 meters or 80 meters. On all three bands, sunrise appeared to have more influence as compared to sunset. Sunrise really shut off the noise. In some cases, the noise ramped up to night levels across several hours before sunset. It seemed as if the quietest time of day was within a few hours of sunrise. Finally, on 80 meters, the (average) noise level would bottom out during the day.   This did not happen on 160 and 40 meters. In all cases, the radio was set to the same preamp position, preamp #2 (maximum gain). I realized that on 80 meters the antenna was an inverted V with the apex at 50', and on 160 and 40 meters, the antenna was a vertical. I have no doubt that the radiation angle is much lower on 160 and 40 meters. The 80-meters inverted V is low enough to the ground that it will be shooting straight up (NVIS). That has impacted the relative noise strength between the two antenna types.

160 meter propagation

General Features

More than HF band it is a medium wave band (MW), (by convention HF bands are from 300 KHz to 30 MHz). It is almost unusable during the day due to the loud atmospheric noise and the strong attenuation due to the D layer of the Earth's Ionosphere. D Region, at night disappears allowing signal reflection. The effect of layer D is selective, according to the inverse of the frequency square, the absorption is maximum at 1.8 MHz, it is therefore dominant, so the best conditions are present when attenuation is less and therefore in periods of low solar activity and as already mentioned during long winter nights, especially in the early hours before sunrise. In summer, in fact, the greater number of hours of light and the higher sun produces a higher level of absorption. I am convinced that the propagation of short waves is all an absorption game, for 160 meters, this is even more true. The relative frequency proximity to the 80 meter band, may lead one to consider that the two frequencies have similar propagation behaviors, none of this, the top band is a world apart from unpredictable propagating characteristics. In the Top List of the DXCC, there are stations with more than 280 confirmed countries, the fact remains that it is a difficult band, governed by absorptions and that requires time, patience and large antennas. Unfortunately, it is not a frequency for everyone. Those who live in historic centers, or in areas with antenna restrictions, cannot work satisfactorily on this frequency. The discussion that follows focuses on the propagation of the space wave, and I intentionally left out some considerations about the propagation of the ground wave, considering it is less interesting for our business.

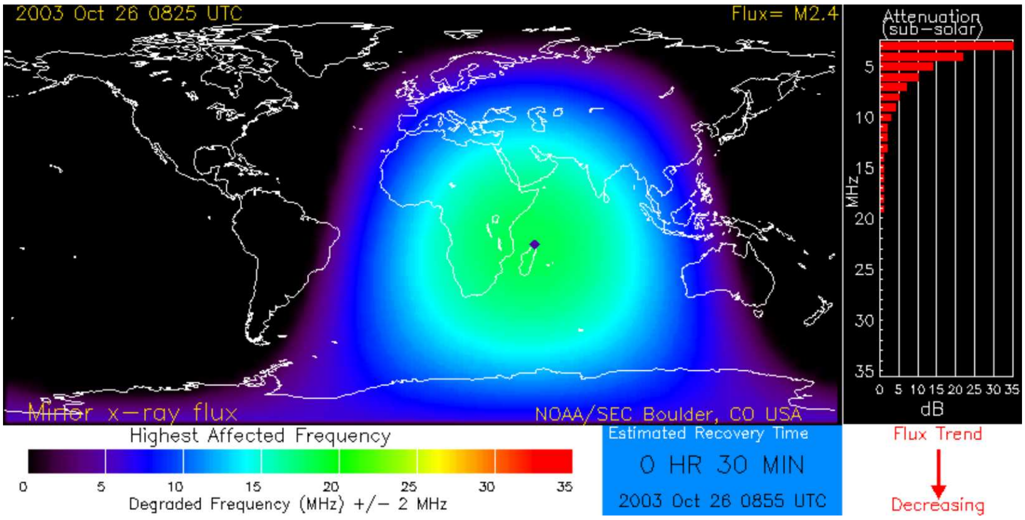


Fig. Cone of maximum absorption induced by D layer, on the illuminated side of the globe. The propagation of the top band is governed by absorptions. (real-time data available on the NOAA National Oceanic and Atmospheric Administration website). Image: NOAA Space weather prediction center.

Attenuation

There are two ionospheric absorptions, the deviative, referring to that part of the ionosphere where the refractive index has significant variations, and the not deviative, which occurs in the D region, where the refractive index can be considered almost constant, the latter is also the most important and has heavy consequences in 160 meter propagation. D layer is as a foggy curtain. In addition, for the Top band, we have an added source of energy absorption, which we will talk about later, it is the absorption due to the gyrofrequency of the electrons. Absorption is a function of ionization, so the maximum absorption takes place in the solar noon at the point of reflection and during the summer season, moreover the absorption index of D region is maximum when the solar activity is high, this since the ionization of layer D is very related to sunlight, after sunset, ionization decays rapidly and layer D vanishes. Region D has an extremely high density of neutral particles (even a thousand times greater than in region E). Solar radiation reaching layer D is attenuated by crossing from the

highest layers of the ionosphere, so ionization is also very low because, due to the high density of ions, they are likely to recombine quickly. When the frequency is low, the electrons of the incoming electromagnetic wave, have a greater chance of colliding with neutral particles, and given the high density of particles, these collisions are very frequent and result in the excited electron losing the energy (which turns into heat) in the collision, before even re-irradiating it. We have well understood that the propagation quality in 160 meter band is heavily affected by changes in electronic density within D region. In daylight hours the D region is very ionized and is the biggest cause of absorption over 160 meters, immediately after sunset, the electronic density falls drastically (although it does not completely disappear) and this electronic residue also affects night propagation. Slight changes in the density of D region, are also of great importance, because they can have a considerable influence on the absorption during the night hours and therefore on the propagation of the signals itself. That is because the frequency is so low that clashes between electrons and neutral ions are very frequent. Remember that attenuation is selective, being inversely proportional to the square of the frequency, and this makes propagation over 160 meters governed by absorptions. Absorptions which are different from summer to winter, influencing the possibility of communications between correspondents from the northern and southern hemispheres.
The best periods for propagation, for example for the long path, should be around the equinoxes, when the level of absorption between hemispheres is equal. Moreover, it is well known that propagation, as well as hourly variations, has considerable seasonal variations.

D Layer

The D layer is considered the primary absorption layer, spanning from 50 to 90 km, with an electron

concentration that rapidly increases with altitude. The electron concentration within the D layer exhibits significant diurnal variation, reaching its maximum shortly after local solar noon and maintaining low values during the night. Even in winter, when the solar zenith distance is substantial, remarkably high electron concentrations are often observed between 70 and 90 km. This could be attributed to the composition and concentration of atmospheric gases. The influence of solar activity on the electronic concentration of the D layer varies at different altitudes. Between 70 and 90 km, solar X-rays play a significant role in ionization, peaking during the solar cycle's zenith. Below 70 km, cosmic radiation becomes more dominant, and the peak concentration occurs when solar activity is at its nadir. Consequently, the interplanetary dispersion of cosmic rays from the galaxy tends to diminish. During geomagnetic disturbances, electron density between 75 and 90 km tends to strengthen at sub-auroral and lower latitudes, owing to the influx of high-energy electrons. The D layer can achieve a maximum density of 10 billion electrons per cubic meter at altitudes ranging from 50 to 90 km. This layer also exhibits a notable abundance of neutral particles due to the rapid rate of recombination between free electrons and ions (capture coefficient). While the D layer's low electron density diminishes its importance for reflecting waves propagating in the ionosphere, it significantly contributes to absorption.

Meteorological effects on the Ionosphere

Meteorological phenomena such as atmospheric gravitational waves of tropospheric origin (AGW), near-biennial stratospheric level oscillations (QBO), stratosphere warming (1) and atmospheric cells (2), have a negative effect on D Layer as they cause increased absorption. The QBO is a variation in the equatorial

stratosphere, it is an east-to-west wind oscillation over a time span of about two years (26 months) and is a source of gravitational waves that generate absorbent perturbations in the E and D layers and can even affect the F region. Thunderstorms, lightning, cyclones and hurricanes are all phenomena capable of generating gravitational waves, just as the sprite phenomenon associated with lightning can have impacts on the chemical composition of the ionosphere. Meteorology therefore assumes considerable importance in phenomena that support propagation in 160 meters.

Stratospheric heating (Strat warm)
In the polar atmosphere and mid-latitudes in the winter months, there may be a significant change in temperature between the tropopause and the stratosphere, precisely where the D region of the Ionosphere begins, characterized by a temperature increase of a few tens of degrees, this temperature reversal has a negative effect on the ionosphere, because it increases the absorption of signals.

Auroral oval effect
Auroral ovals have a negative effect on the propagation of medium waves.
For those connections that lap or even cross the Aurora, propagation can undergo rapid degradation, characterized by a sudden increase in absorption or paradoxically a short and sudden sharp increase in signal intensity caused by inclinations of the auroral ionosphere that can temporarily focus the signal. The result is to have a very unstable propagation subject to rapid evanescence, caused by various effects such as multiple paths, rapid anomalies in absorption, and changes in signal polarization. Coinciding with moments of geomagnetic calm, the auroral zones are of limited size and it is possible that a medium wave signal will spread even in the vicinity of the oval, without being heavily

absorbed. During these periods of very low geomagnetic activity, the auroral zones never widen at low latitudes (in the northern hemisphere the extent of the aurora radio when the K index is less than 2 , never descends under the Arctic Circle and therefore remains geographically limited in the area that occupies the Arctic Ocean) and this allows long-distance communications in various directions, without the signal encountering highly absorbent areas of the ionosphere.

Gyro-frequency

Unfortunately the frequencies of medium waves are subject to the Gyrofrequency (3) (electron-gyrofrequency) of the electron, which is between 630 and 1630 kilocycles, the 160 meter band (in Italy 1810-1850 kilocycles) is very close to this frequency. The gyro frequency is the measurement of the interaction between the electrons moving with circular motion in the ionosphere and the magnetic field dispersing energy, the closer the frequency of the signal to the electron frequency, the higher the absorbed energy. For our latitude, the electron frequency is about 1400 KHz but increases approaching the magnetic pole and in the presence of geomagnetic perturbations.

Space Weather and 160-meter propagation

We know that propagation of these frequencies is controlled by the lower regions of the ionosphere, from D region in the first place, from E layer and in some cases, from the night F region and is subject to solar and geomagnetic phenomena affecting the ionosphere, such as solar flares and their negative impact on D layer, where the intense x-ray flow during higher intensity flares, or greatly increase of relative ionization, deteriorating the level of propagation. It is good thing then, to check the situation of geophysical events, for a clever use of the band. The correlation between the quality of propagation and the solar flux (or the number of

solar spots) is very negligible, since the layers that support the propagation of medium waves are the nocturnal ones of the lower ionosphere. The 160 meters are better in the low periods of the solar cycle, as the noise level is lower, and the geomagnetic field tends to be calmer.

Wave guides

Most long-distance connections in the top band are supported by propagation by ionospheric conduits or propagation phenomena call "Chordal Hop" or even propagation to M. But let us see better what it is. Under certain conditions, signals can enter a waveguide and propagate with low losses within the earth's ionosphere. This type of propagation is much more diffuse than is believed and supports propagation even for the highest frequencies of the HF spectrum.

The phenomenon, which for 160 meters takes place on night or twilight paths, is supported by a complex play of residual absorptions and ionizations. E layer in fact, plays a fundamental role in supporting this mode of propagation since it should be the residual ionization of this layer that supports the diffusion of the signal within the nocturnal ionosphere formed by the ionization of F region. All previous reflections on the quality of the geomagnetic field and auroral conditions remain valid, and the diffusion of signals through ionospheric ducts are supported by geomagnetic stillness.

However, I have had the opportunity to find that sudden geophysical events such as small/medium intensity solar flares can, at least at the first stage, favor this type of propagation since a sudden increase in ionization of the E region, due to the arrival of charged particles of solar origin, they are able to favor the entry of wave trains within the ionospheric guide.

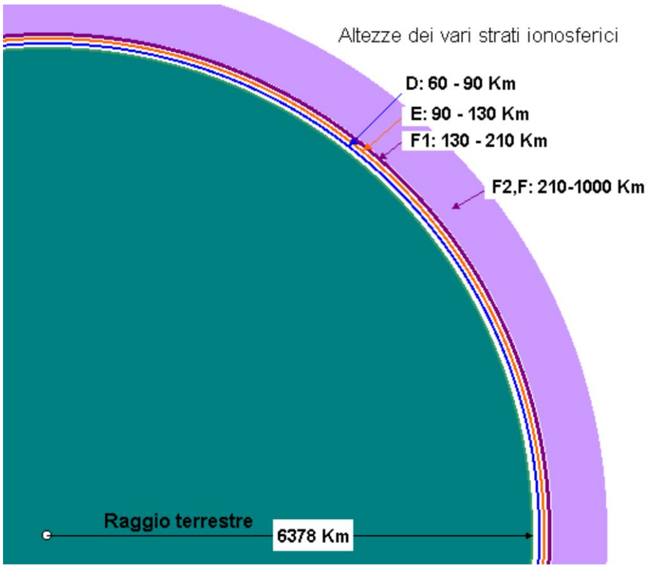


Fig. To better understand waveguide propagation, it is necessary to reflect on the true size of the ionospheric layers, compared to the Earth's radius, and to this end I have reported the scale dimensions of the earth and the Ionosphere. Interesting is an article written by a well-known Canadian OM, Yuri Blanarovich, VE3BMV:"Electromagnetic wave propagation by conduction", which makes an interesting analogy between ionospheric propagation and the propagation of light within an optical fiber. Blanarovich argues that ionospheric long-distance propagation is solely due to this theory. Moreover, Marino Miceli, I4SN, has repeatedly argued that HF propagation could take place differently than conventional theory says.

Irregularity of ionospheric plasma (sporadic E)
E layer is the layer that most supports the propagation of medium waves, and within this ionospheric region the phenomenon of sporadic E occurs. We know that sporadic E clouds are ionospheric plasma irregularities positioned at the height of the E region. As well as stratospheric warming and differences in temperature and tropospheric composition, example can also block, absorb or even support the propagation of medium waves in a completely unpredictable way depending on the circumstances.

Focus

Especially before dawn there may be phenomena of focusing for those signals that come from the West side of the world and therefore from the night hemisphere, due to the increasing radiation pressure (5) along the terminator and that could create a temporary multi-stratification in the ionosphere with an almost parabolic pattern. The American OM call this phenomenon "Skip focusing". The signal for a few minutes can have significant gains but then suddenly decay and gradually disappear swallowed by the gradually increasing attenuation of the D layer. Large irregularities present within the Ionosphere, can give rise to phenomena of focus of the wave trains in transit, these irregularities seem to form more frequently near the terminator.

Noise
The level of radio noise picked up by the antenna and coming from the surrounding environment is particularly important: The main component is atmospheric and natural disturbances, which increase background noise and prevent interesting signals from being heard. Atmospheric disturbance is due to temporal electrical discharges and is therefore subject to wide variations over time depending on seasonal and daily climatic conditions. The countless tropical storms and thunderstorms in the mid-latitudes that occur daily around the earth, generate a high level of static discharges especially in the summer, which make winter nights the best time for listening and searching for DX on the 160 meters.

Curiosity
The opportunity to work in some important international contests such as the CQWW and WPX, gave me the opportunity to find a strange phenomenon in the night propagation on the low bands (160, 80 meters). I detected a cyclic propagation characterized by moments of good propagation to periods of near blackout, with cycles variable of 10/15 minutes. A explanation could be

provided by the so-called Faraday rotation, in other words by phase changes that undergo a signal passing through the ionosphere and which causes periodic and negative fading, or by cyclical variations
in the layers (periodic gradient variations, or height movements, linked to ionospheric undulations) of which I cannot give any explanation now.

Some general information and suggestions

And finally, I try to summarize some general considerations and suggestions, which do not want to be a guide written in stone. I do not have any titles to do so. I have only collected some data that I hope will serve.

- Calm geomagnetic field (6), with K index not exceeding K3
- Check that the K index is low even in the previous 24 hours, the conditions should be better.
- Check the trend of the magnetic field in the previous days, the conditions are better when for a few consecutive days he is calm.
- Check the absorption level of D region
- Low Aurora level, tending not to exceed 4, or 5.
- Constantly check the position of the terminator (grey line), the signals always choose the paths with less absorption.
- Conditions should be better when the solar flux level is not too high (solar flux 2800 MHz) Values not exceeding 140.

Notes:

(1) Strat warm (Stratospheric Heating)
It is the large-scale warming of the winter polar atmosphere; It is a phenomenon that can last even a few days.
(2) Atmospheric Cells
These are atmospheric circuits that transfer heat from low to high latitudes. They are known Hadley's cell (in equatorial zones), Ferrell’s cell (in mid-latitudes), and polar cells (at high latitudes).

(3) Frequency lap (Fg)
Electrons within the Ionosphere move with rotary motion under the effect of the geomagnetic field. At a frequency of about 1400 KHz they assume a uniform circular motion that causes a remarkably high dispersion of energy. Strong magnetic perturbations have the negative effect of raising the value of the Fg.

(4) Critical frequency (Fc)
The critical frequency is the lowest frequency that with vertical incidence is reflected to the ground by an ionospheric layer
(E o F layer).

(5) Radiation pressure
It is the force impressed by solar radiation to the Earth's ionosphere, for propagative phenomena it is interesting the effect that is achieved at the terminator where the radiation pressure changes abruptly, passing from the side in light to the dark one, generating phenomena of focusing.

(6) Geomagnetic field
The geomagnetic field in and around the earth. Its surface intensity is about 32,000 nTesla at the magnetic equator and 62,000 nTesla at the poles. The geomagnetic field can be measured with instruments called magnetometers. The data collected every 3 hours (3 -hour interval, K-index) from a network of magnetometers give the situation of geomagnetic conditions and a quantitative measurement of the level of geomagnetic activity, as this value varies from 0 to 9 on an almost logarithmic scale. It indicates the maximum fluctuation of the horizontal component of the Earth's magnetic field (electromagnetic induction level expressed in nT) relative to a geomagnetic quiet day, measured over a three-hour time interval. The K index is necessarily linked to the specific geographical location of the observatory, so for locations where there are no observers it is necessary to take as a reference the value of the nearest station. A weighted average of the K

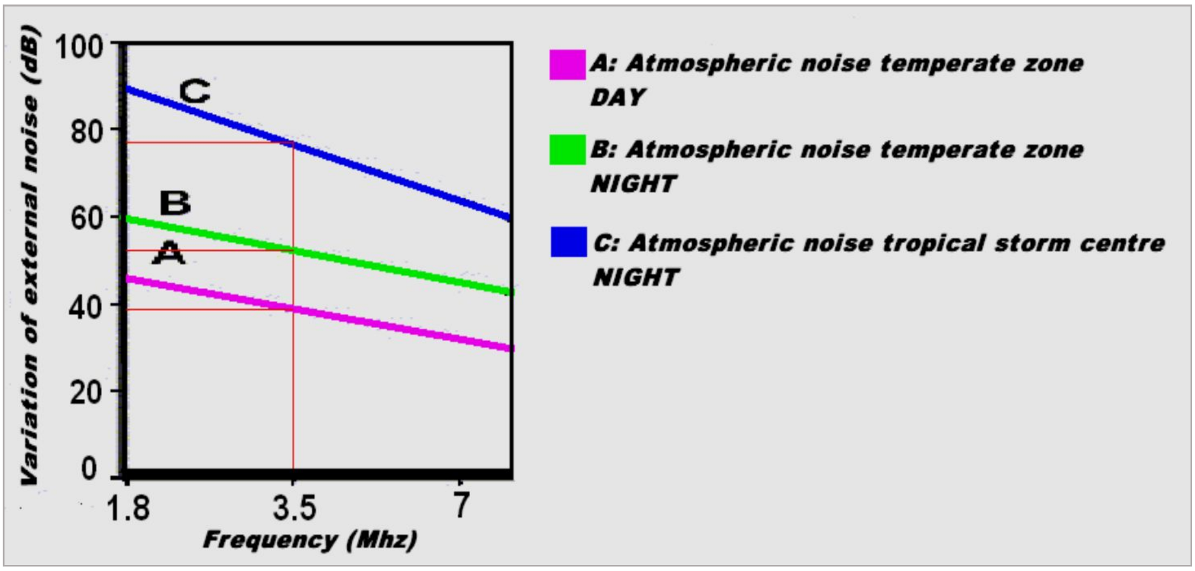
indices of a network of geomagnetic observatories calculates the Kp index (official planetary index) which indicates the overall situation of geomagnetic activity and is available daily in bulletins published on the web network. For better monitoring, A index was introduced, which is based on a larger scale than index K and which provides an average daily value of geomagnetic activity since it is an average of all K indices of the day, the value of index A varies from 0 to 400.

80 meter Propagation

General features

This is the lowest band of short waves, conventionally ranging from 3 to 30 MHz. What was mentioned regarding the 160-meter band can also be partly applied to the 80-meter band. This band is affected significantly by attenuation due to the D layer, although to a lesser extent than the 160-meter band. When the entire path is in darkness, absorption is minimal, offering the best chance for long-distance communications. The 80-meter band is available during the early evening and nighttime. It enables connections to national stations and allows you to receive signals from stations within a radius of up to 1500-2000 km. Toward the morning, propagation opens towards the Americas, Asia, and Oceania. The optimal time for communication is when, during our dawn and dusk, the correspondent is in the opposite time zone. For lengthy connections such as those with East Asia and the Pacific, the most favorable "openings" occur within a limited period around sunrise and sunset. Dx signals then fade a few tens of minutes after sunrise, suppressed by the intensifying D region, which becomes more active with daylight. Leveraging the frequent nighttime openings, especially during periods of low solar activity, allows for excellent Dx connections. Like the 160-meter band, antennas must be exceptionally large for true efficiency.

Atmospheric Noise



Like all low bands of the HF spectrum, the level of background noise is particularly important. In our latitudes the situation is better than at stations located for example in the tropical belt. However, the noise level is decisive in long-distance connections so, it is advisable to take advantage of the possible "windows" that open at certain times, when suddenly atmospheric noise is reduced, for example on the grey line or in the early hours before dawn. In the diagram below I compared the noise level on the low bands considering the geographical location. As a result of tropical storms, the situation worsens as you

approach the equatorial belt, a station in the Caribbean or Indonesia, receiving a much higher number of electrostatic discharges than a station in Northern Europe or Canada, for example, it is possible that a tropical station will not be able to hear our signal because it is covered by the background noise of the receiver. The difficulty of building efficient antennas accentuates the problem of disturbances, so it is important for good traffic to take great care of the receiving system and use low noise antennas if possible.

Grey line effect

When the whole path is in darkness, you have the slightest absorption and therefore there is the best chance for long distances. The maximum possible happens when at dawn and dusk with us, the correspondent is in the reverse

situation. When the sun rises and for a few hours, the F region is dynamic and its refractiveness has a gradient that rises with the sun. On the grey line, there is therefore a sum of favorable factors such as increasing critical frequencies, absorption of the still mild D layer, radiation pressure that causes the ionosphere to tilt. In addition, in the morning, in the terminator belt, the MUF rises rapidly and the refractories are more marked just when the gradient changes sharply. In the 3 summer months (June, July, and August) at our latitudes, due to the short night, there is an effect of almost grey line continues throughout the night, the problem of the summer months is the high level of background noise due to the higher frequency of thunderstorms. The improvement in dawn propagation is due to the peak of signals coming from the west (side in the dark), although it is often confused with grey line propagation it is not a real effect of the grey line but a phenomenon of focusing resulting from the combined effect of refractions on F layer, plus another refractive on E layer, which produce significant gains, this phenomenon, in 80 meters, can normally last 10-20 minutes.
The phenomenon begins immediately after dawn, but in general the sun must have already arisen. Similarly, the phenomenon recurs at sunset, for those signals that always come from the dark side so, in this case, from the east and always subject to the focusing effect with similar duration and chronologically just before sunset.

MUF (Maximum usable frequency)
In the sunlit part of the globe, we find the highest MUF of the day, vice versa the lower MUF, we find them in the dark part. The MUF rises rapidly as the sun radiates the Earth's ionosphere and slowly decreases with night. D region instead, forms slowly as the sun rises but degrades very quickly immediately after sunset. Therefore, for a period that depends on the frequency used, there are favorable conditions for searching for communication over long distances. I have seen that on the high bands (14 –18 – 21 MHz) this time frame, can be 1 hour, even 2 hours,

while it is lower in the lower frequency bands, although for this reason, twilight propagation plays a more key role, especially for the enormous influence of D layer, which on these frequencies is particularly important.

HF fadeout

Solar flares produce strong electromagnetic radiation that increases the ionization of the ionospheric D region, short wave communications typically depend on the reflection of signals on F layer, after having traveled at least twice the D layer. This increase in ionization, combined with the higher neutral particle density, produces an increase in signal absorption in D region during larger flares.
This effect is known as SID, sudden ionospheric disturbance that cause an increase in the attenuation of HF signals, especially on the low bands and markedly on the 80 meters. The effects of this phenomenon described above, are also called short wave fadeout. The fadeout immediately follows a solar flare, develops rapidly but the decline is terribly slow and variable (at least 1 hour), the frequencies most affected, as already mentioned are the lowest of the HF spectrum, the high bands are less affected and sometimes they can also be exempt. An important feature of the Fadeout is that it only affects signals in transit on the illuminated part of the globe. Since in the night part the earth itself shields the ionosphere from the x-rays produced by the solar flare and a consequent reduction in signal intensity in HF bands, supported by reflections in the Earth's ionosphere on the illuminated side of the earth. This phenomenon is called HF Fadeout and determines the lowest frequency that can be used for a QSO. It is therefore useful to control solar indices, especially the situation of activity on the surface of the sun (flares) which are statistically more numerous during the years of high solar activity, and it is one of the reasons why the quality of 80 meter propagation is better in the low periods of the solar cycle.

Predictability of Ionospheric disturbance and critical frequency (Fc)

The electric currents generated by the precipitation of charged particles, alter the properties of the ionosphere the critical frequency of F layer (Fc F) and which determines the MUF for HF propagation. Critical frequency behavior is complicated and depends on the time of day, season, latitude, and nature of ionospheric disturbances. These changes in critical frequency should be foreseen by HF operators to better manage communications, but a reliable forecast is difficult since while it is correct to believe that disturbances occur in conjunction with geomagnetic disturbances on the other hand, it is not entirely certain that there can be a close relationship between local and world K geomagnetic indices and ionospheric disturbances. Severe geomagnetic disturbances may occur with small effects on the ionosphere or vice versa. Ionospheric disturbances are more frequent in the upper part of the solar cycle and often in the second declining phase of the cycle.

Geomagnetic situation

In any case, we have always kept, as a rule, that propagation conditions are better when the geomagnetic field is quiet, this also applies to 80 meter propagation. It is suggested to check A index if the index is above 10 indicates disturbed conditions. The A Index is the average over the 24 hours and index K is the index in 3 hours (2). For ionospheric layers, on the 80 meter band, the best conditions are when the K index is less than 2 and applies to what has already been said for the 160 meters. The conditions should be better when the field is quiet even in the previous 24/36 hours.

Observations on ionospheric wave guides

Long-distance propagation is very often supported by ionospheric ducts and applies to the propagation of the 80 meter band. The conditions for the formation of waveguides are best near the terminator, where the

ionosphere is rapidly evolving, but we have already discussed this abundantly in other paragraphs dedicated to the positive effect of the grey line. There are, however, differing views on the actual formation of these ionospheric ducts, and I had the opportunity to discuss them with some American radio amateurs, who argued that the quality of propagation on the lower bands (80 and 160 meters) is very different from state to state, simplifying the concept, the signals are stronger for stations along the East coast and for stations facing the Pacific. These radio amateurs receive much better signals when the path is predominantly over the sea and outside the auroral areas. The stations located in the countryside, are penalized due to the heavy losses induced by the ground. In the light of these considerations, they argue that the propagation is due to multi-jump reflections, thus excluding a propagation supported by the ionospheric ducts, since, if so, there should be no losses due to the nature of the soil, since the signal propagates exclusively within the ionosphere and consequently there should be no geographical differences. Different, it is true, and I have also observed that the connections that develop on the sea, are favored, as are the coastal stations, but I believe that this is due to a concomitant series of favorable factors. Having the sea close, certainly helps and can sometimes make a difference, the lack of natural obstacles favors the propagation of the electromagnetic wave, especially since water is a much better reflective plane than the ground, and this regardless of any path that made the signal within the ionosphere, also above the oceans should be less formation and therefore the incidence of atmospheric gravitational waves, AGW Atmospheric gravity waves (3), which have the negative effect of increasing absorptions, on the continent instead , the presence of soil and especially mountainous reliefs is a source of AGW that propagates from the troposphere to the ionospheric layers.

Importance of the antenna

We have already mentioned how the installation of an efficient antenna presents objective difficulties deriving from the high wavelength involved. However, for good right-hand traffic it is essential to take care of the effectiveness of the radiant system. The irradiation angle is also important to make the most of the effects of propagation on the grey line, because the marked irradiation angle has the effect of increasing or decreasing the time it takes to take advantage of the advantages of twilight. For stations near the equatorial belt this discourse is even more critical, so much so that the effects of the grey line are for about 40 minutes with a good antenna and only 10 minutes with inefficient antennas (high irradiation angle). In our latitudes (45°) the situation is less extreme (because of Earth's geometry the useful time increases as we approach the poles) and indicatively we can have a useful time of about 40 minutes with inefficient antennas and 1.5 hours with good antennas.

Propagation predictions

The following data are general suggestions, considering ionospheric propagation is not mathematical and that there is always the possibility of abnormal and unpredictable events that can improve or worsen conditions:

- Aurora low level: Level below 5.
- Try immediately after the local sunrise, signals coming from the West, focus effect for about 10-20minutes.
- Try just before local sunset, signals coming from the east, focus effect for about 10-20 minutes.
- Calm geomagnetic situation - Index K below 2.
- Geomagnetic index K <3 even in the previous 24/36 hours (Index A < 10).
- Work on the grey line, along the grey line the absorption is less.

Notes:

1- Solar flares: Activity at the sun's surface is highlighted by the density of sunspots, which appear as dark areas on the photosphere, fluctuating in frequency within a cycle of activity approximately 11 years. They are dark regions because they are "colder" than the bottom: their temperature is of the order of 4000°K, while that of the surrounding surface is 6000°K. Intense magnetic fields are located in sunspots and, on the immediately upper part of the atmosphere, intense flares often occur, producing powerful bursts of radio energy at frequencies between about 5 MHz and 300 MHz Often, during the most intense flares, an intense flow of high-energy charged particles (cosmic rays) traveling at a speed of 500-1000 km/s is emitted: when such particles reach the Earth's magnetic field they cause intense radio disturbances and magnetic storms, with aurora formations. Radio communications can be immediately affected after the flare, or the effects can be felt from one to two days after the flare begins.

2- Geomagnetic indices K and A: The K index derives from data collected every 3 hours from a network of magnetometers that give the situation of geomagnetic conditions and a quantitative measurement of the level of geomagnetic activity and varies from 0 to 9 on an almost logarithmic scale. Index A, on the other hand, is based on a larger scale and supplies an average daily value of geomagnetic activity since it is an average of all K indices of the day, the value of index A varies from 0 to 400.

3- AGW atmospheric gravitational waves: They are neutral pressure waves with a high wavelength (with a period T varying from 10 to 180 minutes) propagating from the troposphere and the mechanism that generates the wave is an oscillation caused by the displacement of an air cell that is moved to its initial position due to gravity and the movements that generate it have various kinds. In the lower atmosphere they are activated by different meteorological phenomena such as thunderstorm formations, action of winds on the Earth's surface and on

mountainous reliefs, cyclonic formations and atmospheric instability. They have the negative effect of increasing absorption.

40 meter propagation

The 40-meter band requires analysis from two distinct perspectives: daytime and post-sunset. The behavior of propagation varies significantly between these periods. During the day, signals tend to arrive at a higher angle, resulting in short propagation. As the sun sets, propagation gradually extends, enabling long-distance connections to become possible during the night. These nighttime connections occur along paths submerged in darkness, facilitated by reflections in the F region. In contrast, during the day, signals curve due to interaction with the lower layers of the Ionosphere, primarily the E region. Furthermore, at this frequency, the attenuation introduced by the D layer, while less pronounced than on the 80 or 160 meters bands, gains importance. Additionally, atmospheric noise, though not negligible at 40 meters, becomes a factor. Consequently, the 40-meter band proves to be both intriguing and challenging, serving as a true testing ground for antennas, receivers, and operators.

Working frequencies and limit frequencies
The reflection characteristics of the ionospheric layers, which vary significantly throughout the day, seasons, and the sunspot cycle, result in propagation that is highly dependent on frequency. For each layer, lower limit frequency (LUF) and upper limit frequency (MUF) values are established. Only within this frequency window between these limits can DX traffic occur without restrictions. The MUF-LUF range encompasses frequencies that, when transmitted vertically, manage to traverse the attenuating D layer twice, reflect off an upper layer, and return with sufficient field intensity despite the D layer's attenuation. The LUF frequency is primarily determined by the attenuation factor of the D layer and is active solely

during daylight hours. It might fall within the range of 10 to 15 MHz, although this can vary significantly depending on transmission power. Increasing power can potentially lower the LUF to lower frequencies, within reasonable limits. For instance, with approximately 100 watts of transmission power, the LUF might be around 5 to 8 MHz. If the power is increased tenfold, the LUF could be lowered by about half. These values differ based on solar activity. When the influence of the LUF cannot be mitigated, communication is limited to terrestrial waves, or a shift to a higher frequency becomes necessary. As for the MUF, considering its fluctuations tied to the progression of the day and the season, it can be categorized as follows:

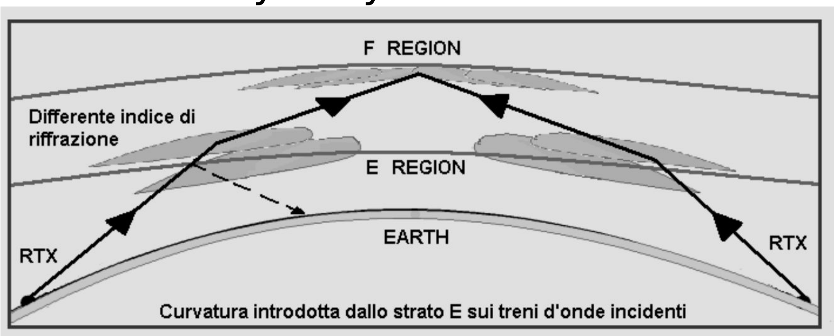
E layer on the 2 ... 4 MHz
F1 layer on the 3 ... 6 MHz
F2 layer on the 3 ... 14 MHz

(Values referring to a relative number of Sunspots of 100)

Not all signals with higher frequencies are reflected; instead, they penetrate the layer. If they fail to encounter a top layer with a higher MUF for reflection, they dissipate into space. As previously noted, the LUF-MUF ranges and the associated propagation conditions pertain to vertical signal transmission. This vertical transmission does not consider the angle of emission, and consequently, does not account for the flow rate. However, if the signal emission angle is lowered, the MUF increases proportionally as the angle decreases.

Irradiation angles

The angle of irradiation of the signal assumes significant importance to figure out the length of the skip, at 40 meters, given the wavelength involved, it is not easy to create antenna systems that radiate at low angles and place the antenna at right height over the ground. Therefore, the irradiation angles of the 40 meters antenna, are high, this partly explains the short-skip daytime connections due to curvatures of the signals introduced by E layer.



Daytime propagation

Daytime propagation is characterized by short skip connections. Connections are possible in a radius of up to 400 - 600 km, but local connections are also possible, even for shorter distances (50 - 100 km), due to the reflection of the signals on E layer, as can be seen from the graph in the next page. Wave trains can be reflected by E region at altitudes around 100-115 km (theoretically the height of E region is between 90 and 130 km), the irradiation angles and the height of the reflective layers figure out the useful area for the connections. My opinion is that these theoretical limits are only indicative, the height of the various ionospheric regions is not always constant, but undergoes variations over time (daily and seasonal), as well as the boundaries between the various layers, are not perfectly delineated, this is due to the fact that the ionosphere, in the same way as the troposphere, is a turbulent gas, where there are various turbulences and anomalies, generated by continuous variations in solar and geomagnetic activity. In addition, there are also stratifications not ionized, but capable of flexing, for the

different refractive indices, radio waves, which contribute to shortening the distances of daytime connections.
Due to the arrangement of free electrons, in defined layers, the angle of incidence and the number of free electrons per cubic centimeter, there are reflections on low stratifications. The deflection to the ground is more marked the greater the thickness of the layer crossed and the longer the path of the radio waves within the layer. For an optic refractive law, longer waves undergo greater bending to the ground as they pass through the middle layers and troposphere, which is why skips are away, which is shorter as the frequency used decreases. The short skip is usually present during the day, since the intermediate layers are activated by solar radiation, towards dusk there is a progressive increase in the distance of the connections due to the progressive disappearance of these non-ionized regions, the near disappearance of the layer, and therefore the reflection takes place in the F region. The ionization index of E region decreases progressively after sunset and as the sun progresses westward, and although it remains a residual ionization, this is no longer enough to bend the wave trains. E region plays a very important role in daytime propagation in 7 MHz, since it determines the length of the connections. The wave trains are diverted by E layer which has enough ionization to reflect signals with this frequency and cannot reach the upper F region. In addition, it must be borne in mind that the layers have distinct characteristics depending on the seasons of the year, in summer D regions and E region are strongly ionized, so on summer afternoons, the strong absorption introduced by D layer, does not allow good connections, despite the high ionization of E layer, which resists even at night. As the elevated level of daytime ionization is slower to disappear, tending to attenuate signals in transit to F layer. This is one of the reasons why propagation in 40 meters is usually better during the winter months.

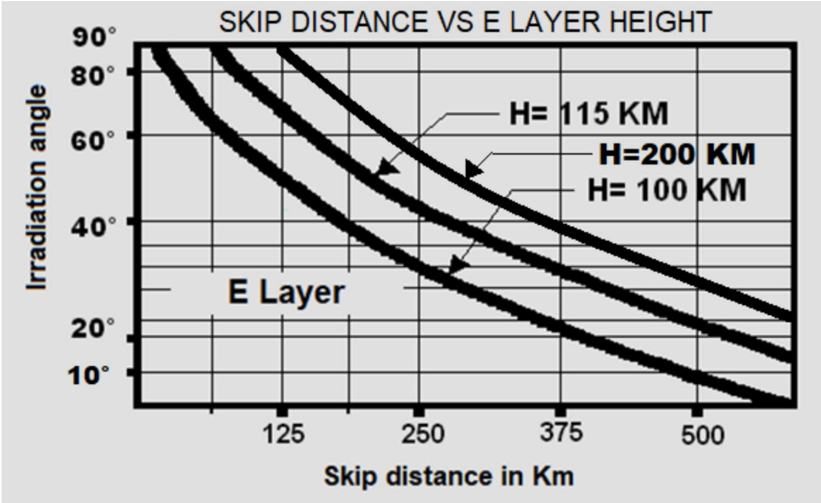


Fig. Skip distance in relation to the height of the E layer.

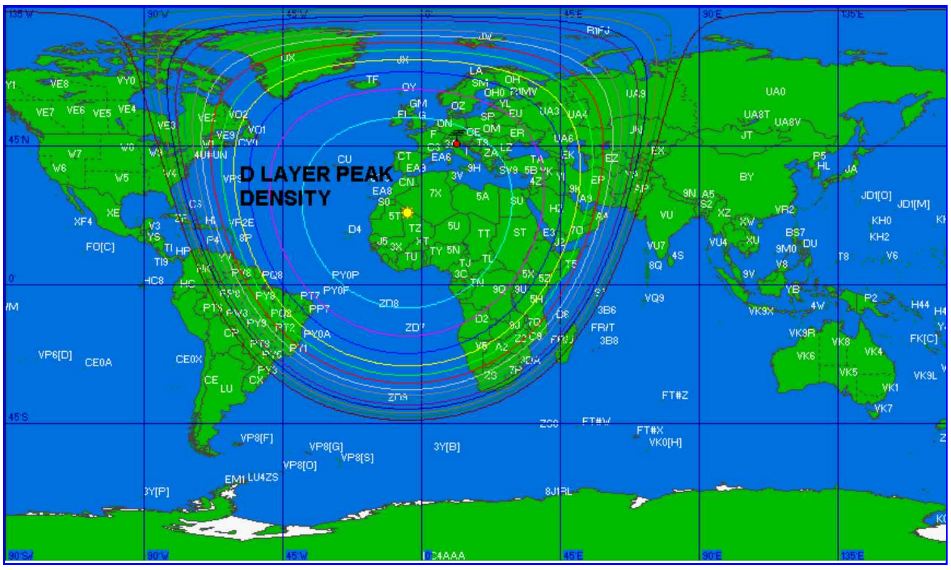


Fig. The map above illustrates the situation of absorption in D region on a summer afternoon, which is one of the causes of the poor summer daytime propagation in 40 meters. *Map created using the DX Atlas software, www.dxatlas.com.*

E region

is defined as that part of the atmosphere between 90 and 140 km high, although these boundaries are arbitrary. In E region, the temperature rises rapidly with altitude, where atmospheric gases are mixed with each other. Above 80 km there is an appreciable dissociation of molecular oxygen O_2 in atomic oxygen O. The level at which there is a maximum concentration of O is between 85 and 100 km. Region E is of great geomagnetic importance because, at these altitudes, there are current systems, such as the equatorial electrojet and the auroral electrojet, responsible for some important geomagnetic variations. E Region can be divided into two parts: the regular E layer and the sporadic E. In turn, the regular E layer can be divided into zones E_1 and E_2. The regular E layer follows the pattern of ionization by solar photoionization and, therefore, shows its maximum critical frequency f_0E around the local noon, During the night the ionization of E layer is drastically reduced, while

the sporadic E manifests itself both day and night. In this region, seasonal variation in critical frequency shows higher values during the summer months than during the winter months. The positive ions that dominate region E are O_{2+} and NO+. The production of the molecular oxygen ion is due to the absorption of C(III) radiation and Lyman b radiation. Additional ions are produced by radiation over wavelengths typical of X-rays. In E region, the variation in electron density is in equilibrium with the average amount of ions produced by recombination processes. Precisely because of this characteristic, one would expect a trend in electronic density in which, during the night hours, it was negligible. In fact, at night the presence of ions and electrons in E region is appreciable. This is supposed to be due not only to electron transport phenomena, but also to ionization caused by the penetration into the atmosphere of meteors, which, by setting themselves on fire, emit energies with wavelengths typical of Lyman a, Lyman b and He II radiation (30.4 nm). Mention should also be made of the presence at this altitude of NO nitric oxide, which, with the O_{2+} ion, gives rise to the formation of the NO+ion. (Some information by Wikipedia).

Attenuation

There are two ionospheric absorptions, the deviative absorption, referring to that part of the ionosphere where the refractive index has significant variations, and the not-deviative one, which occurs in the D region, where the refractive index can be considered almost constant, the latter is also the most important and has heavy consequences in the propagation in the low bands of short waves, for which it presents itself as a foggy curtain. Absorption is a function of ionization, so maximum absorption occurs in the solar noon at the point of reflection and during the summer season, moreover the absorption index of D region is maximum when the solar activity is high, this since the ionization of D layer is very

related to sunlight, after sunset, ionization decays rapidly and D layer vanishes. D region has a very high neutral particles density (even a thousand times higher than in E region).
Solar radiation reaching D layer is attenuated by crossing from the highest layers of the ionosphere, so ionization is very low, also because due to the high density of ions, these are most likely to recombine quickly. When the frequency is low, the electrons of the incoming electromagnetic wave are more likely to collide with neutral particles, and due to the high particle density, these collisions are very frequent and result in the excited electron losing the energy (which turns into heat) in the collision, even before it has even radiated it. Attenuation is selective, being inversely proportional to the square of the frequency.

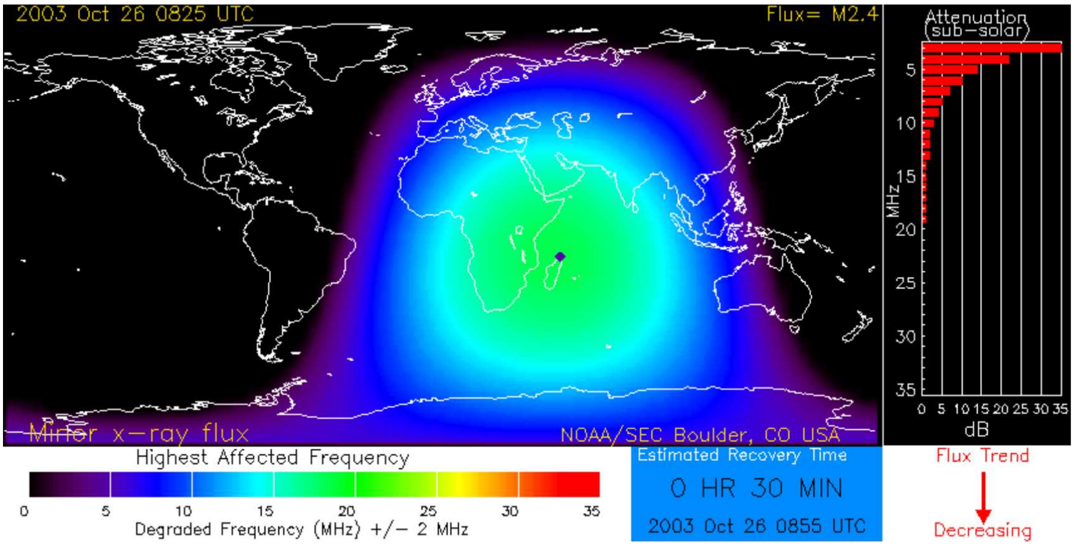


Fig. The map above, depicts the absorption level introduced by layer D (Data provided in real time by NOAA.)

D Region

D layer extends from 50 to 90 km, with an electronic concentration that grows rapidly with height. The electronic concentration in D layer shows an important daytime variation: it reaches its peak shortly after local solar noon, while it keeps extremely low values at night.

In winter, although the zenith distance from the sun is large, extremely high electronic concentrations are often observed, always between 70 and 90 km, due to the nature and concentration of the gases that make up the atmosphere. The influence of solar activity on the electronic concentration in D layer, differs at different heights: between 70 and 90 km solar X-rays are the main source of ionization and this is maximum when the solar cycle is at its peak; below 70 km the most active radiation is cosmic radiation and the maximum concentration occurs when solar activity is at its lowest, so the interplanetary dispersion of cosmic rays of galactic origin tends to decrease. During a geomagnetic disturbance, the electronic density between 75 and 90 km tends to strengthen at sub-auroral and lower latitudes, due to the supply of electrons with a high energy content. D layer can reach a maximum density of 10 billion electrons per cubic meter at altitudes between 50 and 90 km, with high neutral particle density. This layer is not, due to its relatively low electron density, of great importance for reflectivity with regard to waves used in radio links via the ionosphere, whereas it is of considerable importance with regard to absorption, so much so that D layer can be considered the absorbent layer par excellence. D layer has the negative effect of attenuate waves passing through it especially those with lower frequency. At dusk, the D layer is rapidly degraded by recombination.

Night propagation

After sunset, D layer decays rapidly and although more slowly, the ionization of E layer also gradually decays. The ionized layers useful for the reflections of a wave beam, gradually rise due to recombination due to the gradual disappearance of the solar radiation pressure, which is why the connections gradually tend to lengthen after the sun set. Wave trains reach the F region to be reflected (see indicative graph on the range of reflection of the various layers). During the night, we have some favorable

factors for long-distance connection, the absorption of D layer is minimal, and the recombination of F region caused by the ceased solar radiation, keeps only the F2 region at its highest (400 km) active, these factors on the other hand, explain the reason for the lengthening of the paths in darkness, than of Dx connections. In principle, long-distance connections take place on path completely in the dark, or when at least one of the correspondents is near the terminator, in fact on the paths illuminated by the sun, the absorption of D layer and the incidence of the lower layers do not allow the wave trains to propagate over long distances. In addition, the presence of residual ionization in E region, could result in some situations, a kind of wave guide caused by the different refractive indices, trapping the wave trains between the F region and E region, and making them return to the ground after thousands of kilometers, when, for example, along the way the waves encounter discontinuities capable of flexing them back to the ground. In addition, this residual ionization could divert the wave beams by lowering their irradiation angle to region F, lengthening the skip.

F region

F layer begins at a height of about 130 km. At night, F layer behaves differently than during the day. We divided this region into two different layers: F1 and F2, although the electronic concentration does not have very sharp stratifications. F1 layer is the area between 130 and 210 km high and the electronic concentration is of the order of 200 billion electrons per cubic meter. The F2 layer, the highest of the ionospheric layers, is the one in which the concentration of electrons is the densest: its values are between 1000 billion electrons per cubic meter per day and 50 billion electrons per cubic meter at night. The "daytime anomaly" is that the maximum electronic concentration of the F2 layer is often produced one hour after solar noon, typically between 1pm and 3pm local time. Two other changes were experimentally noticed

during the day, the highs of which are around 10 a.m. - 11 a.m. local time and between 10 p.m. – 11 p.m., always local. In the Northern Hemisphere we have the "seasonal anomaly “.
The electronic concentration of the F2 layer, around 12 p.m. local time, is higher in winter than in summer. The "equatorial anomaly" is that in areas between 20 and 30 degrees, both north and south of the equator, the influence of the sun's zenith distance on the electronic concentration of the F2 layer is noticeably different from what is expected. In high latitudes some "anomalies" are observed in the characteristics of the F2 layer, associated with the fall of particles of high energy value. There is in fact a pronounced depression in the electronic concentration of the F2 layer, due to the lines of strength of the magnetosphere and extending over 2-10 degrees in the direction of the equator, immediately after the auroral oval and from noon to all night. Some observations of electronic concentrations, above the height at which its maximum occurs, were made with inconsistently spread radar, with missiles and probes installed on board satellites. These observations show how the electronic concentration decreases exponentially with height. Around 100 km there is a variation in the gradient of the electronic concentration caused by the presence of a shift from oxygen ions to hydrogen ions; the height at which this transition takes place increases with latitude. At 1000 km the electronic concentration is normally of the order of 10 billion electrons per cubic meter. Radio waves are reflected from ionized layers. If the sun has a certain behavior, the ionosphere will have a certain density and structure; other behaviors of the sun, on the other hand, will correspond of many properties of density and structure. So, we can understand that the variations in propagation are related to the following phenomena: alternating day and night (daytime variation) alternating seasons (seasonal variation) alternating periods of high

solar activity with periods of calm (variation of the solar cycle).

Influence of solar activity on propagation

The sun is the "power engine" of ionospheric propagation, so its activity directly influences propagation over all frequencies of the HF spectrum. At 40 meters, however, the incidence of solar activity, is lower than in high bands, indeed, with the solar cycle towards the minimum the openings tend to be longer and more stable and atmospheric noise is less in periods of low solar activity. In addition, the absorption of D layer is less, since being lower the solar flow, its ionization is also lower, as far as the F region is concerned, due to the low activity it also undergoes less ionization, making it problematic to reflect higher frequencies but sufficient to divert the lower frequencies.

40 meters background noise

This is the 40 meters monitoring session began at a local time of 9:00 AM (13:00 UTC) on July 21, 2003. The frequency monitored was 6.992 MHz, right below the 40 meter band. Data was recorded for approximately 4 days. The antenna was my 160 meters vertical which happens to resonate in the 40 meter band. (Local sunrise was approximately 6:12 AM, and local sunset was 8:52 PM).

We can't draw too many conclusions because the data sample only covers a few days in a year, but it can be important to have an idea of the trend. Also consider that the background noise depends on a complex series of factors, such as the location, the type of antenna and receiver and the phase of the solar cycle and the weather conditions.

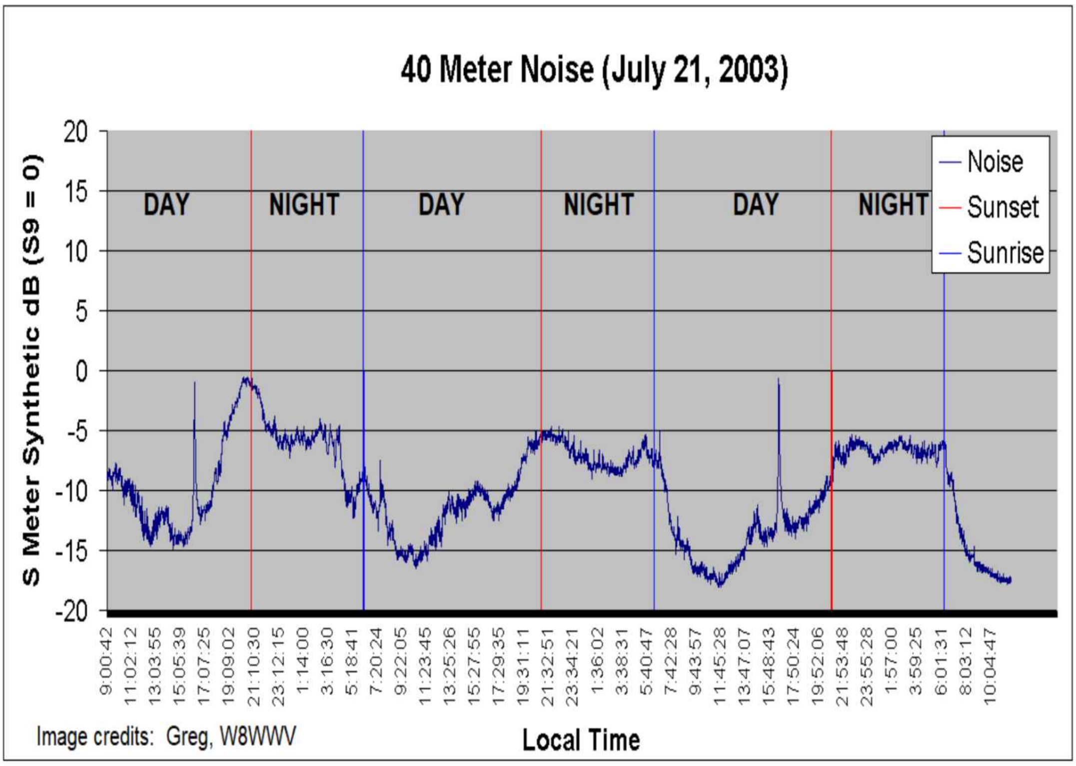

40 Meter Noise (July 21, 2003)
S Meter Synthetic dB (S9 = 0)
20
15
10
5
0
-5
-10
-15
-20
DAY
NIGHT
DAY
NIGHT
DAY
NIGHT
Noise
Sunset
Sunrise
9:00:42
11:02:12
13:03:55
15:05:39
17:07:25
19:09:02
21:10:30
23:12:15
1:14:00
3:16:30
5:18:41
7:20:24
9:22:05
11:23:45
13:25:26
15:27:55
17:29:35
19:31:11
21:32:51
23:34:21
1:36:02
3:38:31
5:40:47
7:42:28
9:43:57
11:45:28
13:47:07
15:48:43
17:50:24
19:52:06
21:53:48
23:55:28
1:57:00
3:59:25
6:01:31
8:03:12
10:04:47
Local Time
Image credits: Greg, W8WWV

Fig. Recorded data for approximately 4 days in 40 meters 6.992 MHz. The vertical lines stand for sunset and sunrise. Thank Greg Ordy, W8WWV.

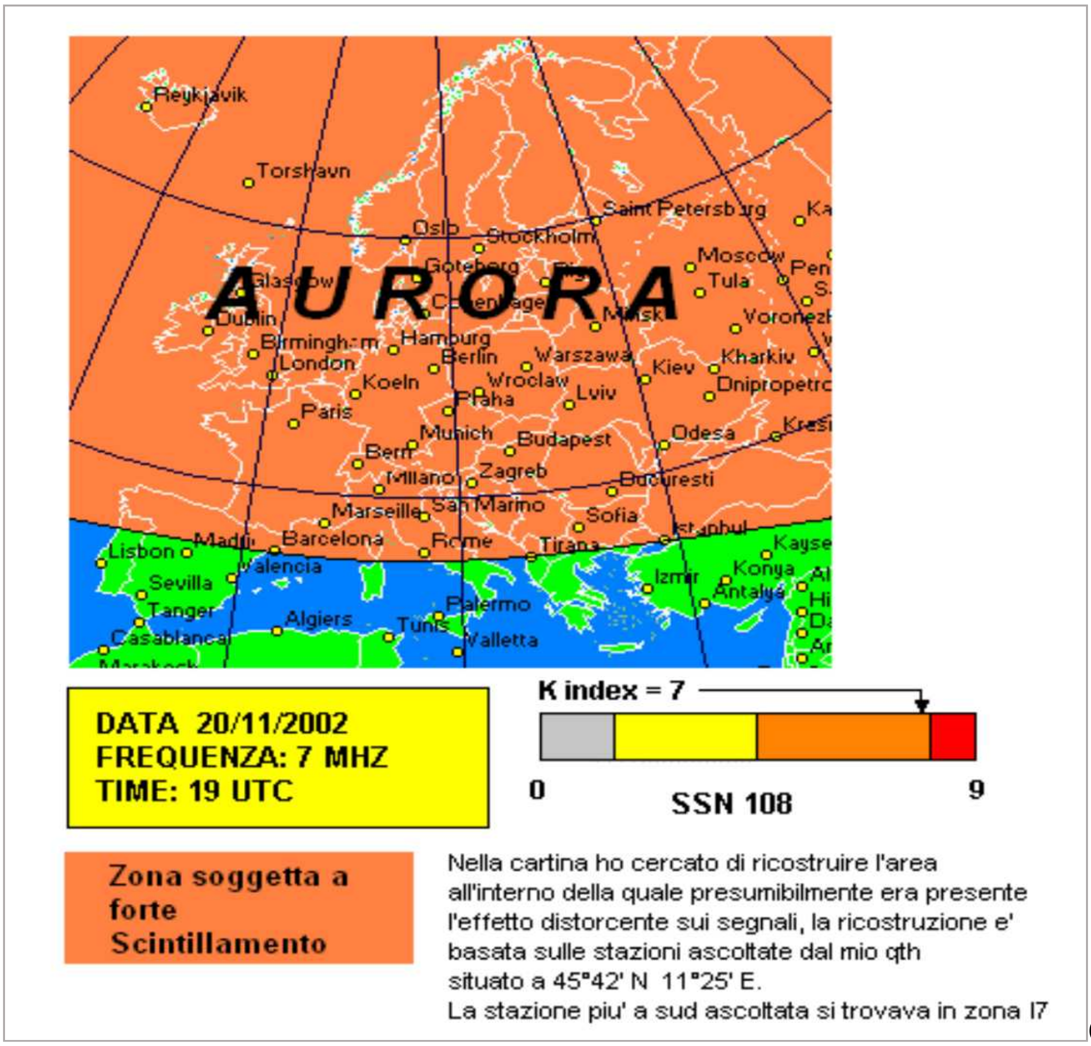
Aurora in 40 meters

In this chapter, I aim to analyze a peculiar propagation phenomenon that I personally observed on the evening of Wednesday, November 20, 2002, around 18:30 UTC. During that evening, I was operating on the 40-meter band. Unusually for that hour, the frequency was silent, devoid of the typical noise associated with it. At 18:51 UTC, I established a connection with station JV5C from Mongolia, partaking in a Special DX expedition for the 840th Anniversary of Chinggis Khaan. The signal arrived exceptionally strong, at 5/9+10dB. This event gave the impression of an extraordinary propagation occurrence originating from the darkened eastern side of the world, characterized by remarkably low noise levels. Substantial signals were also received from various Indonesian stations, including YB0AI from Jakarta, with a signal strength of 5/9+10dB. Meanwhile, the short-skip propagation was still active, and herein lies the most perplexing observation I had encountered on the 40-meter band. (While I had encountered similar phenomena on higher HF bands, such as signals from the West Coast of America via polar paths characterized by "scintillation," this instance was less pronounced.) The signals arrived with noticeable distortion and fluctuation, to the extent that they were incomprehensible at times. Strikingly, this distortion phenomenon exclusively affected short-skip signals, perhaps because distant DX signals from the east (like YB and JT) were reflected by the F region. Stations within a specific area experienced this distortion. I came

across or listened to numerous stations from these regions with distorted signals: I3, I4, I1, I6, IV3, I7, I2, DL, SP, S5, EI, and G. Notably, no signals were received from Scandinavia, potentially due to their location within the auroral oval, which might have blocked the signals. On the other hand, signals from the Iberian Peninsula and especially the Canary Islands remained unaffected by this distortion, due to their greater distance from the influence of the auroral oval. Several Italian radio amateurs corroborated the unusual reception and the anomaly of the event, which, based on the information I gathered, was perceptible up to zone I7. Around 20:00 UTC, while responding to a CQ call from a German station in central Germany, the operator confirmed that my signal was also distorted and informed me of strong auroral activity. For those like me, engrossed in propagation studies, this incident holds significant interest, further augmented by the fortuitous alignment of this phenomenon with excellent DX propagation. Around 23:00 UTC, the situation reverted to near-normal, with short-skip propagation still functional. I picked up robust signals from several Italian stations, even those within proximity, spanning Italy zone 2 and Italy zone 4. Given the nighttime hours, this was an anomalous occurrence. The distorting effect had subsided, due to the presence of low ionized stratifications and the continued activity of the E layer. A potent solar-geomagnetic event momentarily altered the typical characteristics of 40-meter propagation. During this time, I concurrently monitored the higher HF bands (ranging from 20 meters upward), and they were inoperative. I endeavored to delve into this topic by amassing relevant data and tables concerning solar and geomagnetic activity on November 20, 2002, both prior to and after the phenomenon. I aimed to correlate these data with my knowledge of ionospheric propagation dynamics associated with this event.

Solar flares

Activity on the sun's surface is evidenced by the density of sunspots, which appear as dark areas on the photosphere, fluctuating in frequency within a cycle of activity of eleven years. They are dark regions because they are "colder" than the sun surface: their temperature is of the order of 4000°K, while that of the surrounding surface is 6000°K. Intense magnetic fields are located in sunspots and, on the immediately upper part of the atmosphere, intense flares often occur, producing powerful bursts of radio energy at frequencies between about 5 MHz and 300 MHz Often, during the most intense flares, an intense flow of high-energy charged particles (cosmic rays) traveling at a speed of 500-1000 km/s is emitted: When such particles reach the Earth's magnetic field they cause intense radio disturbances and magnetic storms, with aurora formations. The map of solar radiation emissions



due to flares appears much wider than that occupied by sunspots.

Map created using the DX Atlas software, www.dxatlas.com.

Unlike the radiation from most celestial radio sources, which is not polarized, the radiation associated with solar flares has circular polarization, being caused by the spiral trajectories of the electrons that follow the local, intense, magnetic field associated with the flare. In any case, solar flares give rise to a jet of electromagnetic radiation, which ranges from the HF field to X-rays and gamma rays as well as the expulsion of matter from the solar corona, all this is emitted in interplanetary space and therefore also in the direction of the Earth, whose magnetic field captures the plasma that aligns following the lines of force of the Earth's magnetic field, focusing over the

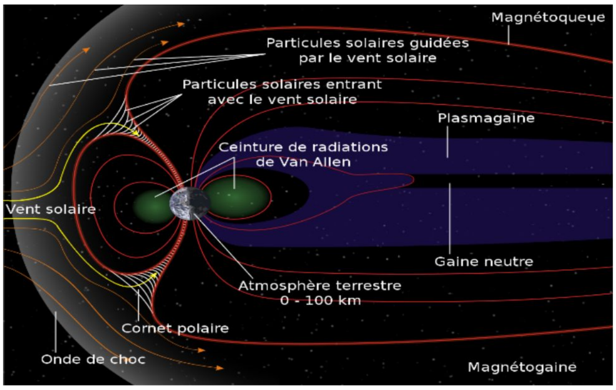
poles, near the auroral oval. The explosion of energy that occurs during a blast is enormous, comparable to an atomic explosion of ten billion megatons. Radio communications can be immediately affected after the flare, or the effects can be felt one to two days after the flare begins. By convention solar flares are divided into three classes, C, M and X which depend on the amount of energy flow developed.

Class C flare is the least powerful and does not immediately affect the ionosphere, although the emitted particles may affect the ionosphere several hours later.

Flare class M is a medium-energy Flare and is enough to influence the Earth's ionosphere immediately after the event, but also to produce delayed effects of solar radiation.

Class X flares are the most powerful and destructive and can cause severe geomagnetic storms and long communications blackouts.

The electromagnetic radiation of an active Flare, ultraviolet rays, X-rays, visible light and radio spectrum, travel at the speed of light and reach the earth with a delay of about eight minutes, so that the effects on the ionosphere can begin while the Flare is visually observed.



The figure left above, shows the Earth's magnetosphere, with the lines of force induced by the solar wind, centered on geomagnetic poles. Our planet and its atmosphere are immersed in this plasma, so it is plausible that all radio propagation events are closely related to the dynamics and interaction of: Sun – solar wind – Geomagnetic activity – Ionosphere - earth. The ionosphere is also not inert, but in the same way as the Earth's troposphere is a constantly moving gas, subjected to solar radiation pressure and continuous perturbations and interactions, as well as the conventional schematization of the various regions (layers D-E-F) and more than anything didactic and indicative, does not correspond to the real situation, which is extremely dynamic, where the heights and boundaries between layer and layer , are not always well delineated and are subjected to continuous variations. The flow of energetic particles is concentrated in the polar zones, since captured by the force lines of the Earth's magnetic field conversing towards the poles. (Image Wikipedia public domain).

Geomagnetic activity

The Ionosphere is a magnetopause, i.e., a plasma immersed in the geomagnetic field, so the reflection of signals in ionospheric layers, directly depends on magnetic activity. A magnetic perturbation, although not strong, agitates the ionospheric plasma and breaks the uniformity of the layers. For an analysis of propagation conditions, the following indices come into play, solar and geomagnetic: Solar Flux, A index, Kp index, solar wind speed, number of spots, X-ray emission.

Aurora

The solar wind brings a large amount of charged particles to earth, which are electrons and protons. This wind is generated by the solar corona which is usually extremely hot.
The solar plasma arriving near the earth, deforms its magnetic field, there is a compression of the lines of force in the part exposed to the sun, while on the dark side the lines of force stretch. The plasma particles do not penetrate directly from the illuminated side, but they are conveyed by the magnetic force lines and move away to the dark side and eventually plummet into the Van Allen bands, where, with secondary precipitation effects, they thicken around the geomagnetic pole (78.5° N-69°W, at the far north of Greenland). The area of greatest ionization density forms the auroral oval, which is located around the geomagnetic poles and its extent depends on solar activity. On Flares (Flares) on the solar surface around the spots or due to overheating of the corona, the solar wind Increases with the consequence that the volume of plasma also increases, this for the earth, means magnetic and ionospheric storms as well as auroras important. The Auroral oval, due to the intense particle precipitation, widens to the south, the intensity of ionization is extremely high, so much so that in VHF, in some cases, auroral curtains are used to reflect the signals. The phenomenon occurs at an approximate altitude ranging from 80 to 150 km, within E region or at the top of D region. Normally auroral phenomena occur around geomagnetic poles (65 - 70 degrees), during strong geomagnetic storms the auroral oval can widen southwards up to 45 -50 degrees of latitude. What we have talked about can also be called Radio Aurora, while the visible Aurora, is a fluorescence that occurs at the height of E region, due to the transfer of energy, emitted in the form of light by electrons emitted by the solar corona (X-rays and gamma rays) that collide with the molecules present in the Earth's atmosphere, the phenomenon of visible aurora is to be attributed more

than to solar flares, to energy emissions from the holes of the solar corona.

NOAA

All the data collected comes from NOAA (National Oceanic and Atmospheric Administration) which through a network of satellites (NOAA POES) in low altitude polar orbit (850 km), conducts real-time monitoring of solar activity and geophysical events.

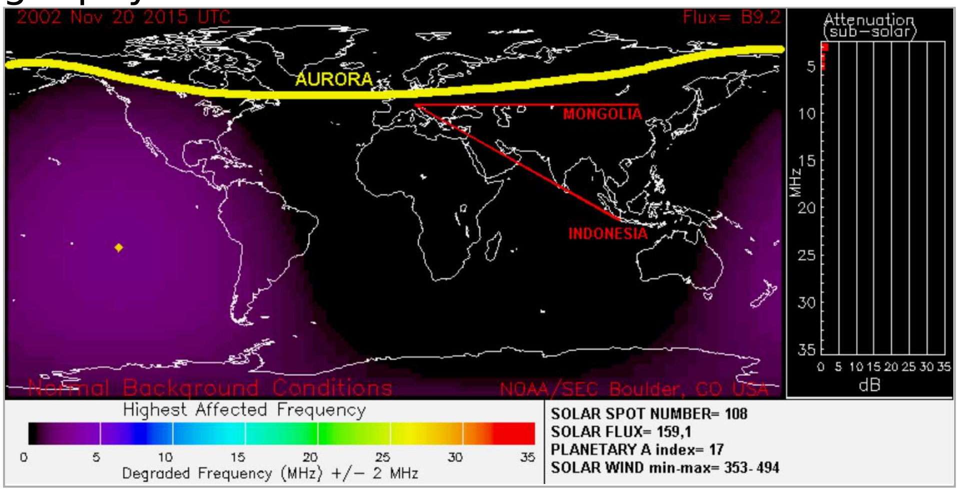
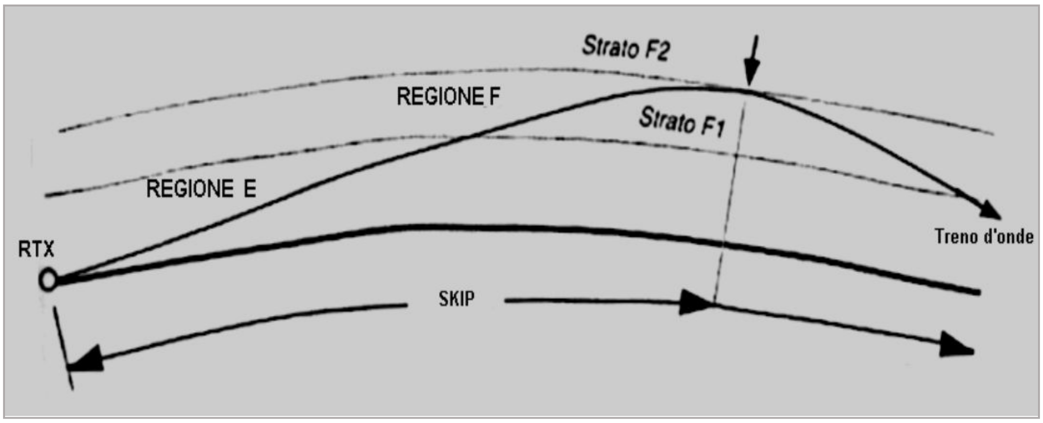


Fig. The map shows (purple color) the area where D layer is active, that corresponds to the sunlit areas and their frequencies subject to greater absorption, the data were collected by the NOAA website and report the real situation at 20.15 UTC on November 20, 2002. I reported the approximate extent of the auroral oval whose intensity was maximum (value 9/10) and the paths of the signal's right eastwards, on the dark side. I also reported solar activity data for Wednesday 20/11/02, the value of the A index, (which is an important indicator of geomagnetic activity was at 17 (not high but indicating an active geomagnetic field) and then rising, at values around 50 the next day but the most obvious thing is Wednesday 20/11/2002 in the late evening the K index reached a value of 7 which means strong geomagnetic activity, in fact while the K index is a more immediate index that for evaluations of this kind takes on a more significant role than the A index which is useful for longer-term forecasts. Image: NOAA Space weather prediction center.

Considerations

In the early evening of Wednesday 20/11 at 18.11 UTC, there was a solar flare of class M1, whose energy triggered a geomagnetic disturbance with negative impacts on the Earth's ionosphere even in the following days, however, for a limited period and immediately after the phenomenon, there may have been a positive impact such as to favor the propagation over the 40 meters, due to the concurrent of some favorable events. The increased intensity of the solar wind caused by the Flare has stirred the ionospheric plasma, broke the uniformity of the layers and thus caused the ordinary MUF to increase, favoring reflection in F region (signals coming from the east, were curved to us by the evening F layer).



In addition, the increase in the absorption of D layer caused by the particles emitted by the solar flare, on the illuminated side, may have blocked some of the noise coming from the illuminated hemisphere, from us, being already in darkness for a few hours the level of D layer was negligible, and this is especially important for the lower bands. This may explain the total absence of noise present in the band during the event (blocked by the high absorption of D region, from the illuminated and closed part to the poles by the auroral hood). It should also be said that the triggering solar event is a Category M1 Flare, which is a flare of the medium type, normally the flares that induce total and persistent blackouts on communications are X type, abnormal flares of extremely high energy. So, in our latitudes, the propagation could at least temporarily and at the first stage, have benefited, more than deteriorating, due to the solar flare. The negative effect lasted in the following days, when the situation stabilized (in a negative sense, with the increase in geomagnetic activity). In addition, a possible increasing level of ionization at the height of E region (Under normal conditions the ionization of E layer, after sunset gradually decreases to become transparent for 7 MHz)), caused by the sudden increase in solar flux, not yet sufficient for the reflection, but able to curve the signals that pass through E layer, with the effect of lowering its angle of incidence towards the F region and favoring the DX. This confirms the fact that the progressive increase in ionization of the

E region, has led to short skip reflections present at 23 UTC.
In addition, a kind of wave guide could form between two regions with a different gradient, between E layer lower, and F region at the top, capable of transporting wave trains for spread reflection for thousands of kilometers of distance. I am not able to establish with certainty whether the contemporary auroral event and the propagation right eastwards, are related, it could also be a simple coincidence, although the close dependence of radio propagation with solar events and geomagnetic activity leads me to think that everything is related. Just as I am not entirely sure that the strong distortion of the signals is directly attributable to reflections on the auroral oval, the signal propagated by the aurora, which is reflected, appears strange and subject to a rapid distorting fading caused by multiple reflections on the auroral cloud, which is not stable, but moves quickly with different directions and speeds. This phenomenon is also called "Flutter fading". Or it may also have occurred in our latitudes (what happens for those signals coming from the American West Coast and that lap the poles) a strong agitation of the magnetic field with a strong instability of the ionospheric plasma and agitated electric fields (due to the geomagnetic storm caused by the Flare) causing in rapid succession a continuous variation in the refractive index due precisely to the scintillation, or the phenomenon could be due to the interaction of both hypotheses. It would have been interesting to have had a chain of beacons such as the one managed by the NCDXF (Northern California Foundations) on high bands, which would have allowed to better monitor the dynamics of propagation paths and signals, as I normally do for experimentation on higher frequencies. In any case, understanding solar phenomena connected to radio communications is an extraordinarily complex thing. It is not yet known how all forces interact, often good propagation conditions are known when the solar flux and

all geomagnetic indices indicate that the propagation should be bad, or vice versa. This is because, like weather forecasts, HF propagation prediction is not an exact science.

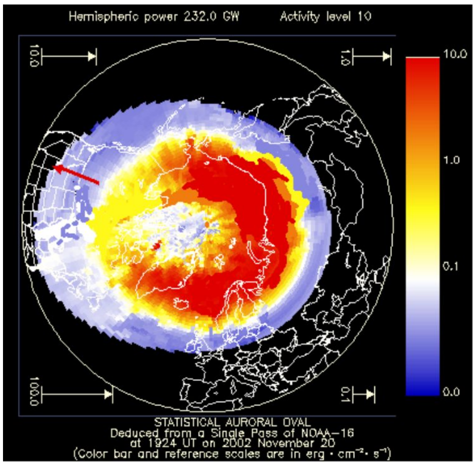


Image credits: NOAA - USA

Graphics

With the aim of analyzing events with more details, in the following tables I collected data relating to geomagnetic activity related to Wednesday 20 November 2002. I report the image of the Class M1 Flare that occurred at 18:11 UTC and that generated the geomagnetic anomaly. The image of the aurora, as well as the graph of several magnetometer worldwide, from which it is clear that from

a situation of geomagnetic quiet, we move to a remarkably disturbed situation (from 18 UTC in conjunction with the space weather observations and the events heard in 40 meters (the anomalous events in 40 meters correspond chronologically to the data reported on the diagrams and recorded by the instruments) also confirmed by the other graph that shows the flow of X-rays and from which you can see the flares.

Mogel – Dellinger effect

Mogel - Dellinger effect is a disturbance of the ionization of the ionosphere due to the powerful solar eruptions associated with flares that cause a strong ionization of all layers. D layer becomes blocking for all frequencies. The Mogel–Dellinger effect typically manifests itself with an unexpected improvement in propagation conditions across all bands and can last from a few minutes to a few hours.

Distance effects in 40 meters - Experiments with WSPR

In this chapter I would like to talk about some experiments conducted with WSPR. Let us see first how it works. WSPR stands for Weak Signal Propagation Reporter. It is a software used in beacon mode with low power transmission, in HF and in medium waves. The transmission protocol provides for the sending of the station name, the first four characters of the locator and the transmission power expressed in dBm. The program can decode signals with S/N up to -28 dB. The stations, automatically send the receiving data to a central database called WSPRnet, which includes a map with real-time receptions. I used this technology to analyze some of the 40 meter propagation behaviors by referencing some stations.

Some tests
I have chosen two stations as a reference, located at different distances and in beacon mode, that is, active 24 hours a day. With a distance compared to my QTH of about twice as much as each other. I took as a reference the DL1FX station, located in the southwest of Germany, in Hesse at 500 kilometers far away and an English station, G8VDQ, in London at 1078 kilometers. I monitored the WSPR signal for a full day of 24 hours and I made graphs where interesting things emerge. (The experiment was done with the summer Ionosphere, in early August 2013).

Data analysis
The first thing that appears is how distance influences the behavior of the Ionosphere and a skip difference of about 500 kilometers, can lead to almost opposite propagation behaviors. The only common thing, are the large oscillations in the intensity of the received signal, but the

thinner black curve, shows the trend of the signal that shows the trend of propagation:

> **DL1FX**: The graph shows that the signal strength increases throughout the day and then disappears after sun sets and reappears again when the sun rises. So, we have a total night blackout. The beacon reappears after sunrise. There is a hysteresis at sunset and a hysteresis at dawn of opposite sign, due to the timing of ionization/recombination of the ionospheric layers. You can see also a "grey line" effect after dark.
>
> **G8VDQ**: In this case the beacon was received for all 24 hours. There were no overnight blackouts. In fact, the behavior was opposite to DL1FX with a signal that tended to increase during the night hours. There were no differences in the grey line, but a spike during the middle hours of the night.

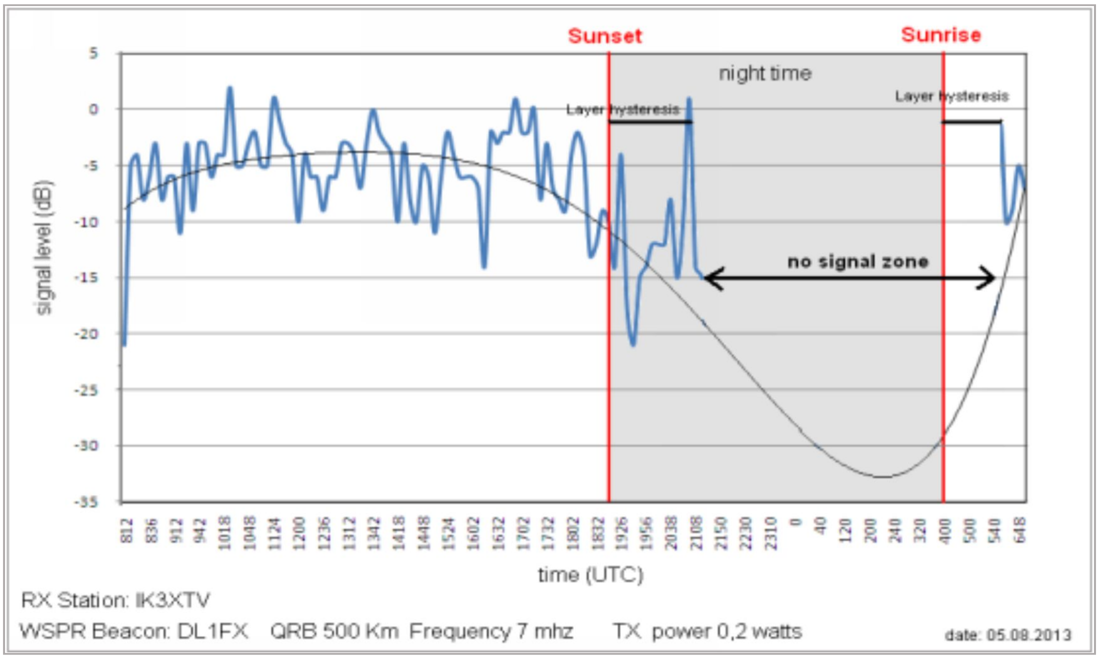


Fig. Graph of German station DL1FX that transmitted with 0,2 wats of power. With oscillation of the signal intensity up to 23dB. DL1FX transmits with a G5RV antenna.

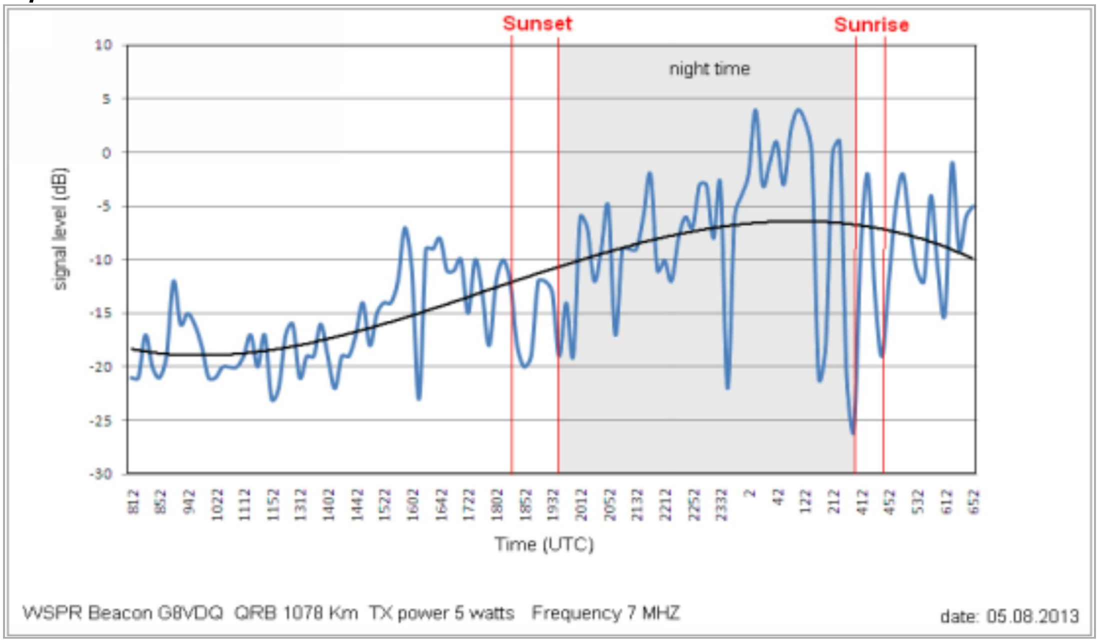


Fig. Graph of the English station G8VDQ, that transmitted with a power of 5 watts. Ionospheric oscillations cause a change in signal level up to a maximum of 30dB.

WSPR experiment with DL1FX repeated years later but with winter Ionosphere

The experiment with DL1FX was repeated in winter in December, with quite comparable results. I always used DL1FX as TX and this time the station IZ3EAW/B reception in WSPR beacon mode because the path is the same as the 2013 experiment. Distance is 550 kilometers. You always see an area of hysteresis after sunset and before Sunrise and an area of silence that coincides with the night hours. The first experiment with the summer Ionosphere was done in 2013 while this winter Ionosphere experiment in 2020.

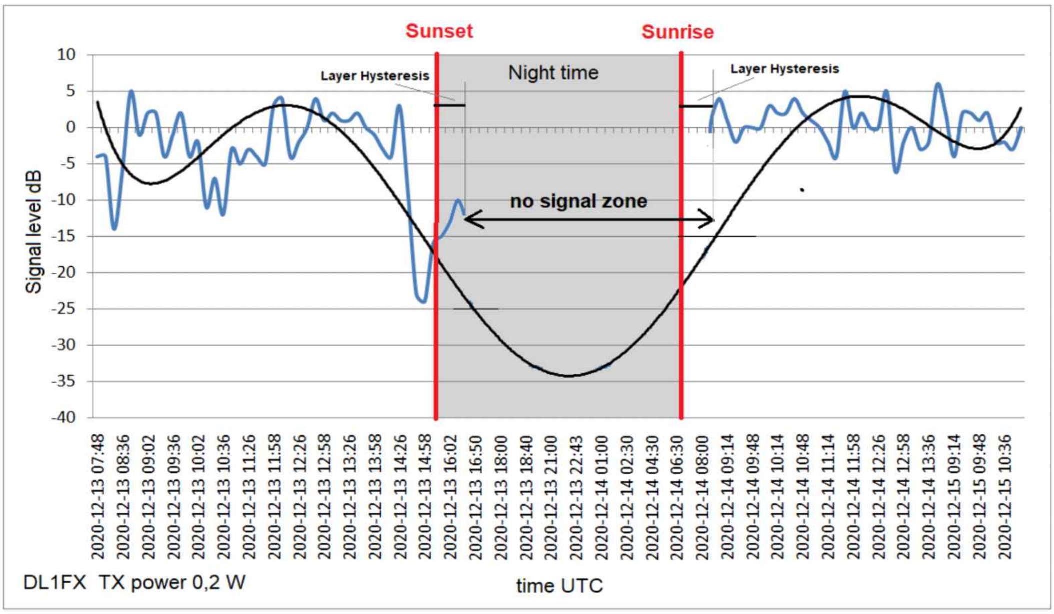


Fig. Chart of the 2020 DL11FX reception experiment in Winter season, receive from December 13 to December 15. Signal received from IZ3EAW/B WSPR station in Beacon mode (setup: KIWI-*SDR with an antenna system*

*of 4 interlaced loops and LZ1AQ*preamplifier*) The distance between DL1FX and IZ3EAW/B is 550Km.*

Reception experiment over more days in winter: DL1FX received from IZ3EAW/B

To better see the behavior of the winter ionosphere, I did another WSPR experiment. I needed two WSPR beacon stations and I found the usual DL1FX and as other station, I always used IZ3EAW/B, listening data over 24 hours for 13 days. The graph shows that the DL1FX signal is received only during the hours of maximum insolation, from 10 am local time until 3 pm. The DL1FX signal was received only during the day. The night path was completely closed. There are significant daily variations, both as the average signal level, and as the duration of the opening time. Propagation varies significantly, day by day. Days alternate with a higher average signal and longer openings, and days with shorter openings.

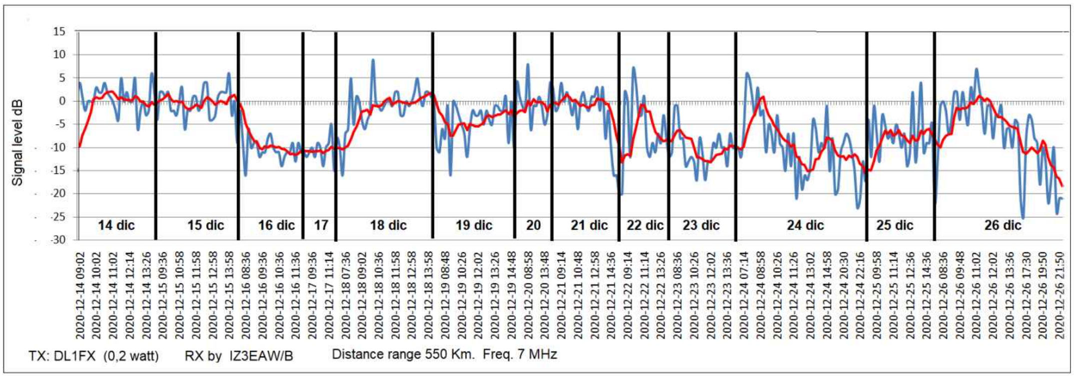


Fig. Graph of the WSPR reception experiment in DL1FX station beacon mode received by IZ3EAW/B. Distance between the two stations, 550 kilometers. Continuous reception h24 for 13 days.

Study with WSPR in 40 meters over medium distance

This is a special test, conducted in December 2020 using the transmission of DL1FX received to the Canary Islands by EA8BFK, on the 7 MHz. The time interval examined and shown in the chart covers 7 days, 24 hours a day. It is a medium distance route, about 3000 kilometers. For me, EA8 is a Dx for the 40 meters. The first thing that comes up is that the path opens at night. The path is always open even in the transitional periods, that is, between the two sunrises and the two sunsets, which are obviously different between Germany and the Canary Islands. Note the great instability of the ionosphere that introduces profound variations in intensity, variations are so wide because the low power transmission of DL1FX.

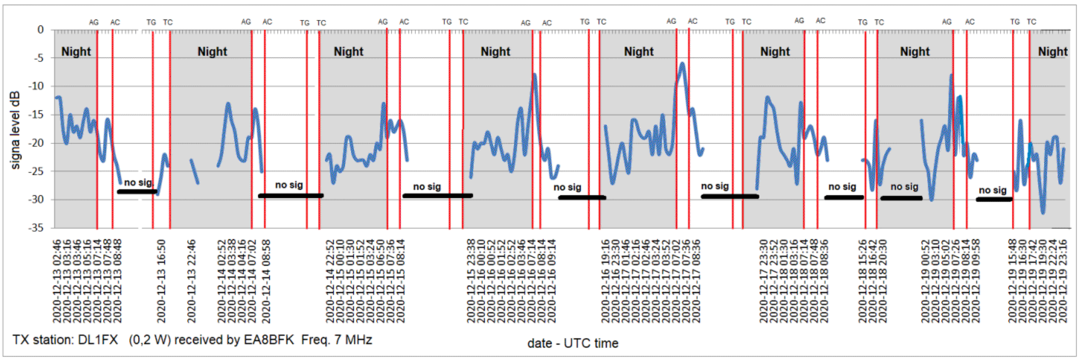
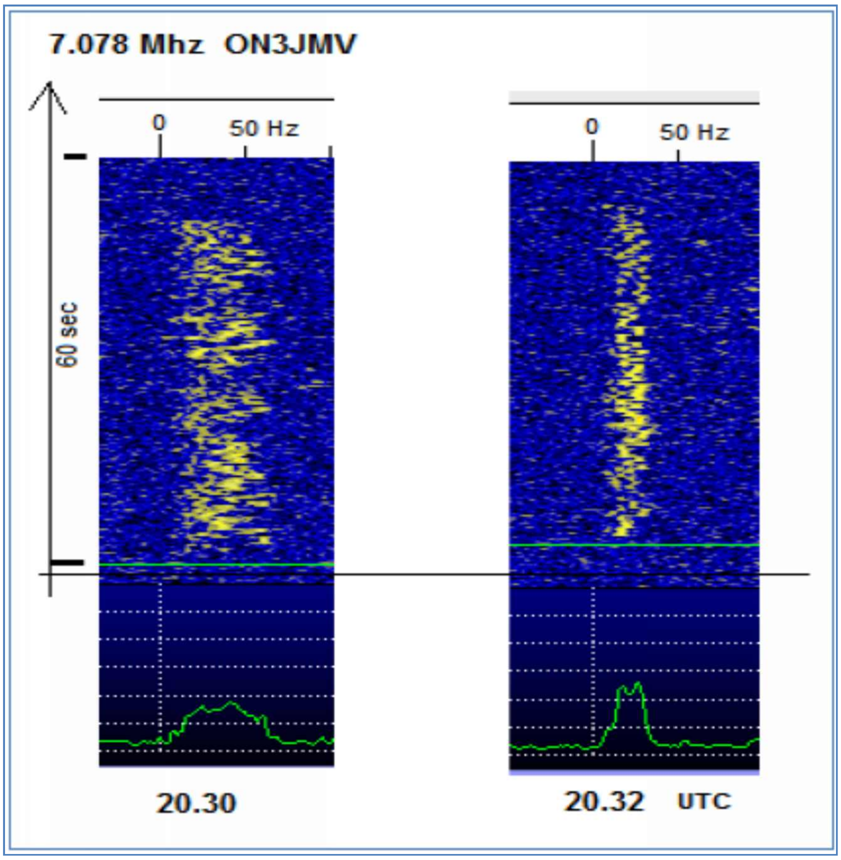


Fig. The graph shows the DL1FX signal received in the Canary Islands. The vertical red lines indicate the time of sunrise and sunset. To understand the chart, you need a small legend:
AG means Sunrise in Germany, AC sunrise Canary Islands, TG, sunset in Germany and TC sunset in the Canary Islands. The areas obscured in grey, are the night hours. The horizontal segments, with the largest black line, are the hours without any received signal.

Doppler spread phenomena at middle latitudes

I have seen the signals on the waterfall several times in various digital modes: It is as if the received signal suddenly breaks down. It often becomes undecodable by software. This issue also occurs in mid-latitudes and appears to be frequency independent. This behavior occurs both at short / medium distances and at long distances, over 10,000 kilometers. It is as if at a certain point, the radio frequency energy found an anomalous wave in its path. The phenomenon is more easily explained for the short / medium distance due to masses of hot and cold air colliding. The ionosphere is immersed in these phenomena such as to cause the scattering effect of the signal with the relative increase in bandwidth and therefore loss of data. In general, the increase in fading and band noise causes these effects on the signal. These anomalies can be caused by phenomena of low- and high-pressure areas, which are met along the way. The scattering from ionospheric irregularities tends to cause the signal to arrive from different directions, increasing the signal doppler. The signal undergoes a doppler shift due to the drift motions of the ionospheric layers involved in the reflection of the electromagnetic wave. From my analysis it is seen that the longitudinal motions of the ionosphere produce negligible contributions in doppler. On the other hand, vertical drift motions are more critical; in this case the frequency shift can reach up to a few tens of HZ and therefore give rise to not negligible distortions, as in the case of the figure below.

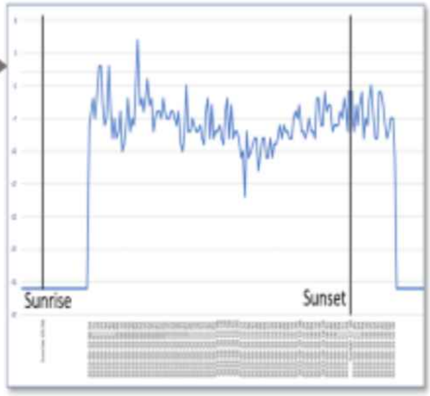


7.078 Mhz ON3JMV
0
50 Hz
0
50 Hz
60 sec
20.30
20.32
UTC

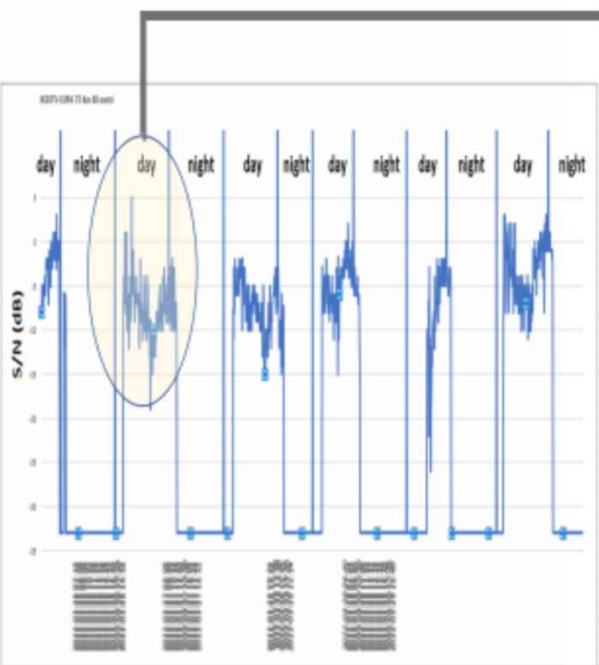
Fig. We have now understood that the ionosphere is dynamic and unpredictable. This is an example of reception on 40 meters with QRP digital transmissions (WSJT mode JT9), because I can observe the signals on the waterfall. I often see phenomena like the one shown in this figure. In this case it is a Belgian station, ON3JMV. At 20.30 UTC, I observed a strange signal, different from all the others. The transmission has a bandwidth of about 50 HZ instead of the usual 20 HZ expected from JT9 mode. Something has changed the spectrum of the signal. Then two minutes later, at 20.32 UTC (right image), the phenomenon was disappeared and the spectrum returns to normal, at 20 HZ.

Propagation via the ionosphere in 40 meters already occurs for very short distances (70 Km.)

It is interesting to observe how in 40 meters the propagation of the signal occurs only via the ionosphere, as can be seen in the experiment illustrated below.This is the signal transmitted by IK3XTV in WSPR mode with 0.5 watts and a Windom antenna, received by I3JPA about 70 kilometers away. This experiment was repeated for several consecutive days, and I got the same results. We can see that the signal is received only during the day, when the sun activates the ionosphere. After sunset, the signal disappears quickly.



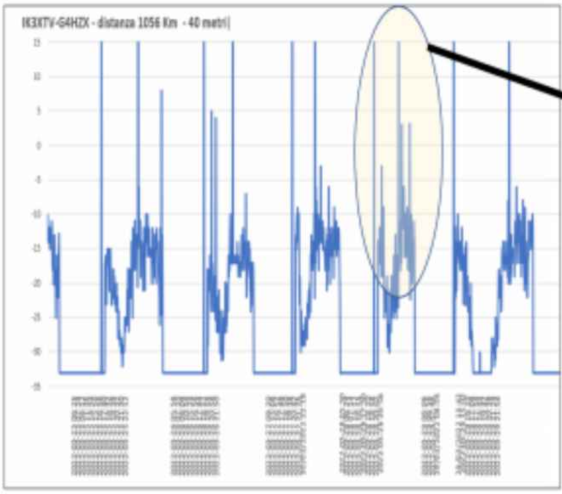
Zoomed image of a single day trend. The signal has a step shape, with a slight negative dip with a maximum peak at -19dB at 14.24 local time.



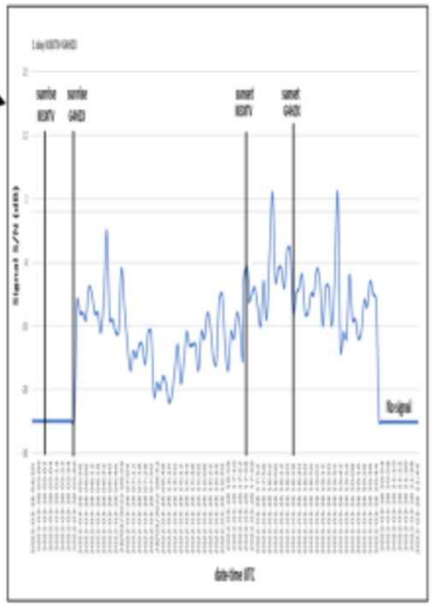
Freq. 7 MHz distance 73 Km.

Ionospheric focusing phenomena

Signal transmitted by IK3XTV in WSPR beacon mode, with power of 0.5 watt and Windom antenna, on the frequency of 7 MHz and received by the English station G4HZX. The signal reception curve H24 shows a prevalently diurnal propagation, which lasts after sunset for a few hours. Furthermore you can see a V-shape with a negative peak at the second part of the morning, until about noon. It is interesting to note the positive peaks, probably due to ionospheric focusing phenomena. (Experiment carried out in March 2022).



The trend of the signal shows a V-shaped trend, with the lowest peak occurring in the second part of the morning until around noon.

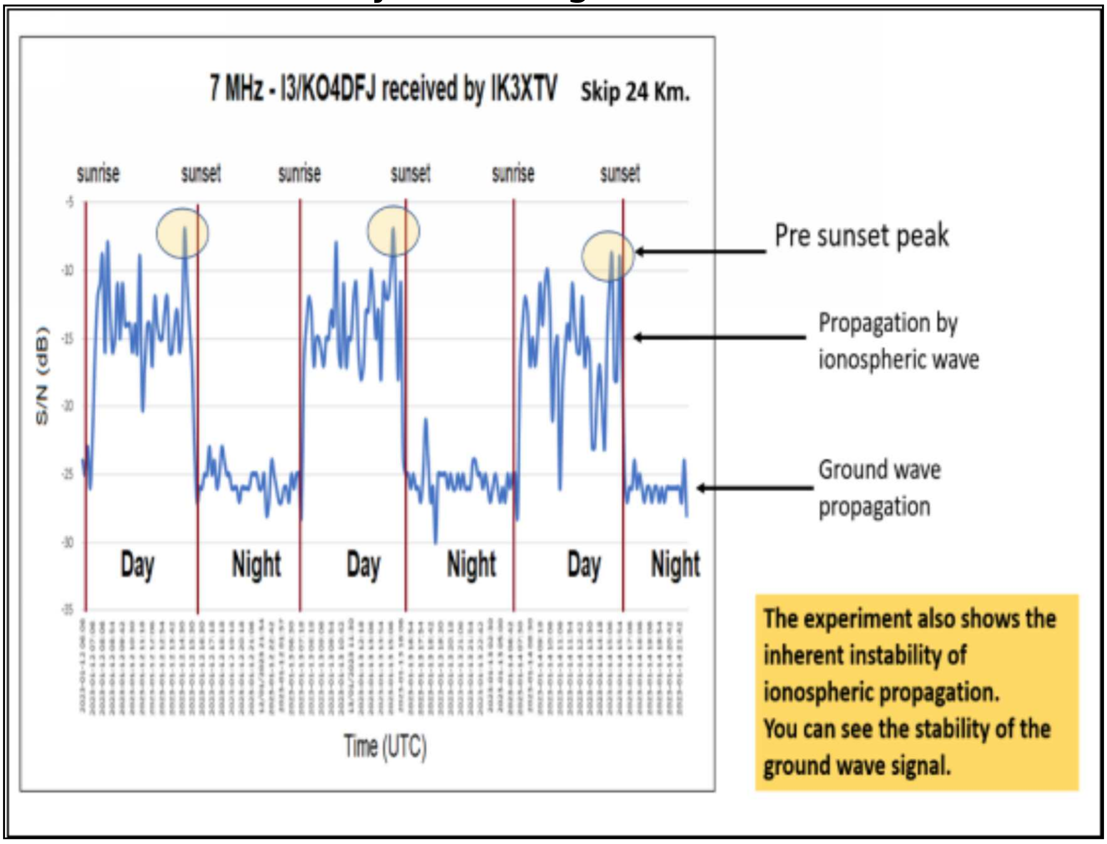


Zoomed image of a single day trend. Signal peaks can also be seen, probably due to ionospheric focusing phenomena.

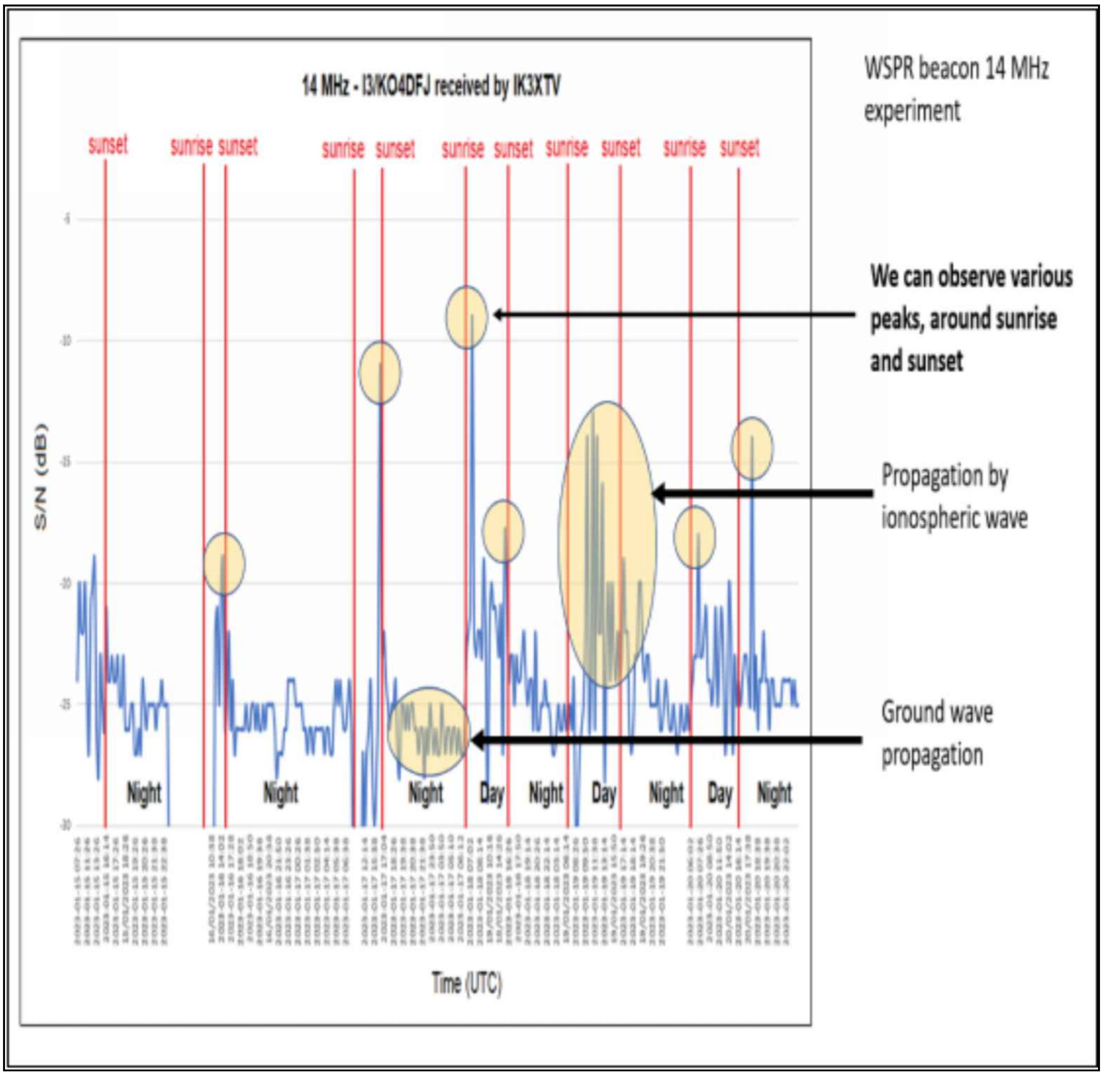
Freq. 7 MHz distance range 1056 Km.

The role of the ionosphere in very short amateur radio contacts

We have already seen how on 40 meters, on skips around 70 kilometers, there is only the ionospheric wave component. Ground wave propagation suffers too much attenuation. On shorter skips (24 km), as in the case reported below, the ground wave still works, but only during the night hours, during the day the ionospheric component prevails. From the graph, we can observe how the propagation by ionospheric wave is significantly more unstable than the ground wave. These are always experiments with low power WSPR beacons. I used the WSPR I3/KO4DFJ beacon, which transmits with a power of 0.2 watts, at 24 kilometers from my receiving station.



Now let us see, for comparison, what happens if we do the same experiment with the same station, but on a higher frequency, such as 14 MHz. On 14 MHz the propagation footprint is less defined, the variation between the ground wave and the ionosphere wave is less defined and the ionospheric wave seems more efficient than at 7 MHz. We see frequent signal blackouts during the day, but much less during the night. The propagation is heavily affected by weather conditions.



20 meter propagation

General features

It is the most popular and widely used band for long-distance communication; therefore, it is also the busiest band. The influence of the D layer is less important, and the band can be open day and night, especially during periods of high solar activity when the openings are more

frequent. When the sun is quiet, propagation conditions are favorable, especially during the daytime hours, and DX (long-distance) connections take advantage of the twilight zone. The area of silence limits connections to distances greater than 700 - 1000 km. Especially in the morning, national short skip connections are possible, for example, with Southern Italy and Sicily, and of course, with Europe and the Mediterranean Basin. There is an excellent chance of connections in the afternoon with signals coming from the western side, from North America (USA and Canada). Connections with the Pacific area are possible, especially in the morning hours. However, it is difficult to generalize since propagation is always unpredictable, as it varies with changing seasons and solar activity. Conditions can be noticeably different, but this also adds to the charm of our job. The higher HF bands exhibit "daytime" characteristics, but during high solar cycle years, the performance can be exceptional, leading to continuous openings. Among the HF bands, 20-meter propagation is the easiest to predict due to its frequency being in the center of the spectrum; it exhibits predictable behavior and allows for more solid and lasting connections. All these factors contribute to making the 20-meter band the primary frequency for DX communication

TEC (Total electron content)

Measurement of total electronic content, TEC (1) detected at a height of 450 km (F2 Region), responsible for long-distance propagation in the 20 meter band. The greatest concentration is visible (yellow-red zones) along the equatorial belt and in the illuminated part of the globe. There is also a night residue in the equatorial and temperate belt, responsible for the night openings over 20 meters. The data refer to a survey of May 2002, therefore at a high phase of the solar cycle and during spring/summer in the Northern Hemisphere. For this reason, the night residue is accentuated in the northern

hemisphere.

Disturbances

Disturbances play a less key role than low bands. However, noise (2) is not negligible as shown in the noise graph, where we can see that the most important noise is that generated by human activities. I have taken as a reference an average value, which however can increase depending on the location of the station, for example, in large conurbations, industrial areas, etc. For good Dx traffic the most advantaged stations are found away from the large population centers, where the urban noise is almost absent. From curve A, on the other hand, we get the trend of atmospheric noise which is less important than the lower frequencies. The use of an efficient antenna system has the advantage of being able to mitigate the impact of noise because it is possible to orient the beam and thus achieve noise filtering.

Propagation and solar activity

Like all other bands, it is influenced by the solar cycle, however the influence of the solar activity has a less extreme impact than the higher bands. In the high part of the cycle, the band is open for all 24 hours. In the lower phase of the cycle, the band openings are reduced and the DX should be possible at the best times of the day, when the conditions are more favorable (reduction of ionospheric absorption, favorable conditions along the path, then in the hours before and following the sunrise and sunset, we have advantage from the twilight propagation, as usual. Good conditions also in the middle phase of the solar cycle (the phase before the maximum peak and the phase that follow). During the maximum sunspots number, the 20 meters has a trend that combines the characteristics of 40 and 15 meters, because it is open simultaneously both eastwards and westwards for most of the day and allows short skip connections, like 40 meters during daylight hours. The

band opening for those signals that arrive at a wide irradiation angle. To make the most of these peculiarities, the best results are obtained by combining a simple half-wave dipole with a directive antenna and managing the switching of both. During the lower part of the cycle the openings are concentrated towards west, then the illuminated part of the globe and a single directive antenna is enough. As far as, I'm told so far, I consider the 20 meter band to be the best for the entire solar cycle.

Seasonal and daily variations

It is well known to all HF operators, how propagation is influenced by the motion of the seasons; We know that the conditions of propagation follow a marked seasonal and daily trend. However, it is difficult to schematize an overall trend of propagation and in this is valid also for 20 meters because ionospheric propagation does not allow certainties, but above all because the conditions vary from Winter to Summer with different impact, according to the high or low phase of the solar cycle. However, I would like to try a summary of the band behaviors:

Low phase of the solar cycle: summer openings are good for all continents, thanks to the fact that the MUF are just above 15 MHz and therefore the band is open for a long time, despite the possibility of night openings, it has daytime characteristics. When the cycle is low, the openings are usually during daytime. In winter, DX is to be searched during daylight hours, because the band tends to close immediately after sunset.

High phase of the solar cycle: in summer, especially in the central hours of the day, the MUF tend to rise too much and therefore the 20 meter propagation tends to close, the openings are concentrated in the early morning and towards the late afternoon/evening. With the sun in high activity, there are exceptional night openings, with

low absorption. In winter, the band tends to remain open for the entire day. At every phase of the solar cycle, therefore, conditions depend on the seasons. In principle the conditions are better in winter, this is because in summer we have the phenomenon of the Summer Depression (3) (please see notes at the end of this chapter). Once the phenomenon was mistakenly called winter anomaly.

Geomagnetic activity

The general rule of the calm geomagnetic field is still valid. The uniformity of the layers, guaranteed by a situation of geomagnetic quiet, is important to support propagation over long distances even on the 20-meter band. This also means a low aurora level, which favors communications that take advantage of paths near the poles. Especially at the high latitudes, which for Europe correspond to the stations found in the Scandinavian peninsula, the auroral situation assumes particular importance, as confirmed by the data that have reported me many stations active from these sectors and that report to find real blackouts in conjunction with intense auroral phenomena even for the 20 meter band. The Scandinavian radio amateurs themselves have confirmed to me how in some cases the aurora is able to favor short skip connections, due to reflections of the signal on the auroral curtains.

Contribution of E layer

Here we can partially repeat what has already been said for the 40 meter band. There is always the magic effect, although less marked than 40 meters, of a favorable contribution introduced by the residual ionization of E region, which could trap the signal in a ionospheric duct formed between E layer and higher ionizations, at about the height of F region. This often occurs during twilight hours and seems to be accentuate at equinoxes. The transmitted signal with irradiation

angles of at least 30°, can enter this E-F layer duct and travel with low attenuation for very long distance. The E region is also responsible for short propagation during the day, especially when the solar flow is high (High phase of the solar cycle). The intense solar activity can raise the critical frequency of E region up to frequencies close to 14 MHz, allowing it to return to the ground at a short distance.

Behavior of the Ionosphere

The Ionosphere consists of three main layers called D, E and F. The highest is F layer and under certain conditions is the one that most supports HF propagation over long distances, but as we know, ionosphere is a very selective medium. Free electrons in F region interact with the radio signal, and the effect of this interaction is the curvature of the wave train. Electrons react more easily with lower frequency radio signals. Consequently, a slight ionization of F layer, is enough to propagate the waves at a lower frequency as is the case at night, when the residual ionization of F region is enough to support the propagation in the bands from 160 to 40 meters. Free electrons do not react so easily with the fastest oscillations of higher frequency radio waves, so that for the propagation of signals over the 20 meter band, higher electronic density is required and as the frequency increases, the required electronic density becomes higher. Electronic recombination occurs more quickly in the F region, because the density is higher, it is present exclusively during daylight hours and supports daytime and short skip propagation in bands from 160 to 40 meters. Normally the electronic density of E layer is not enough to reflect the waves of 20 meters and higher. In D layer (present only during the day) the recombination is even faster, and the density is even greater, therefore the free electrons are very few. Region D absorbs lower frequency signals especially in bands 40-80-160 meters, bands of 80 and 160 meters are closed during the day, due to high absorption. The main source of ionospheric

ionization is ultraviolet energy from the sun, and even small variations in the energy level received have a significant impact on the quality of HF propagation. In those days, when energy levels are higher, the ionization of F layer increases and improving HF communications (MUF rises).

Conversely, if UV energy decreases, the HF communications deteriorate, and the bands above 15 meters become unusable. Propagation over 20 meters is less affected by these variations and in many cases the band may be the only one that can be used for long-distance communications.

I intentionally reported this propagation model in a simplistic and very conventional way, in fact the experience and practical observation confirmed to me that propagation very often develops in a completely different and unpredictable way, compared to this classic model. Small variations in energy level are enough to cause large variations in the behavior of ionospheric plasma. Electronic recombination of the various layers is not so linear, affecting both reflections and absorptions and other agents, of a meteorological nature can improve or worsen conditions. Practice has taught me that the band of 20 meters, perhaps because of its middle position, is the band that is closest to the traditional model of HF propagation and, it is the easiest frequency to predict, however, forecasting ionospheric propagation is more difficult than forecasting the weather.

Importance of solar flux

Although there is a linear relationship between the number of spots and the solar flux (4), I prefer to rely on the values of the flux since it is a more direct measure. We know that the quality of propagation depends on the amount and intensity of solar radiation coming from the sun, and solar flux is a measure of that intensity. Solar flux values can range from a minimum value of 50 to a maximum value of 300. During the highest peaks of

sunspots, the flow is always higher than 200, allowing excellent communications throughout the high HF spectrum, from 20 to 10 meters. During the minimum period of sunspots, flux values vary from 50 to 80, making communication difficult in the bands above 40 meters. An increase in flow, over a period of several days, indicates an improvement in long-distance HF communications. For example, MUF will rise abruptly if from a flux value of about 110, we move to a persistent value of 130 for several days, vice versa, MUF will decrease if the flow drops below 90. I report a table showing the propagation conditions based on the values of the solar flux.

Solar flow	Expected propagation conditions
50 - 70	Bands above 40 meters unusable
70 - 90	From poor to quite good propagation in 20 meters and lower bands
90 - 120	Quite good propagation up to 15 meters
120 - 150	From sufficient to good condition on all bands up to 10 meters
150 - 200	Excellent conditions up to 10 meters with possible openings via F2, even in 6 meters
> 200	Open propagation on all bands up to 6 meters

WSPR experiment in 20 meters

The graph below refers to data collected from the WSPRnet database and is an example of receiving a WSPR beacon mode station DL1FX with 0,1 watts of transmitting power, received from a station in the Canary Islands, EA8BFK. The experiment tends to highlight the variability of the ionosphere with significant hourly and daily oscillations. This path, open propagation during first morning at about 08:00/09:00 UTC, and the propagation path closes around 15:00/16:00 UTC. The monitoring period covers an interval of 14 days. From 13/12/2020 until 26/12/2020. The experiment is extreme given the very low power of TX station DL1FX. To report the wide daily oscillations in signal strength, in the order of 20/25 dB.

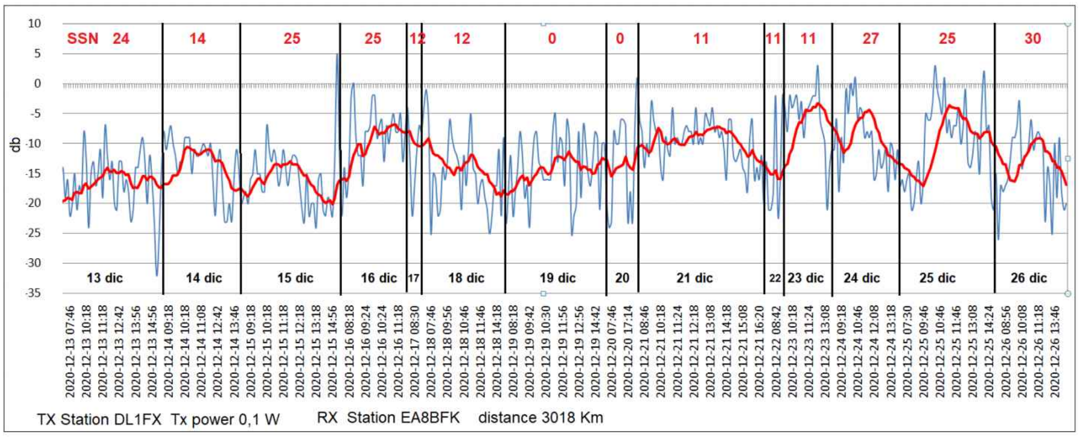


Fig. DL1FX signal at extremely low power (0.1 watts) G5RV antenna, received in the Canary Islands. The red in numbers, shown at the top of the chart, indicate in number of daily sunspots (SSNs). The two WSPR stations, are active 24 hours a day, without interruption.

<u>Notes:</u>

(1) TEC: Total Electron Content
The number of electrons along the path of the electromagnetic wave measured in electrons/square cm. TEC is used to determine the delay and changes in the direction of a wave propagating in the ionosphere, so it is an important reference value to quantify the level of ionization of the Earth's ionosphere and consequently the quality of propagation.

(2) Noise
<u>Atmospheric Noise</u>
Atmospheric noise is caused by thunderstorm electrical discharges.
So, it depends on the frequency of reception, the time and weather conditions, the season and geographical location. In the HF bands, this noise is characterized by short pulses that can be heard above the background noise.
<u>Artificial Noise</u>

The amplitude of artificial noise decreases as the frequency increases and varies from position to position. The noise comes from electric motors, neon signs, power lines and localized ignition systems a few hundred meters from the reception antenna. They usually propagate along the electrical grid and taking advantage of the ground wave, however, for frequencies below 20 MHz, propagation can also take place through ionospheric reflection.

Galactic Noise

This form of noise originates outside the earth and its atmosphere. Noise reaching the Earth's surface extends from ~15 MHz up to 100 GHz (for lower frequencies it is limited by ionospheric absorption and for others by atmospheric absorption). Galactic noise is dominant in the frequency range from 40 to 250 megahertz, over 250 megahertz, the internal noise of the receiver predominates, under 40 megahertz, instead atmospheric and artificial noise must be considered.

(3) Summer depression

The strong summer solar radiation expands the ionosphere (the ionosphere is a gas that when heated expands) and causes greater rarefaction of ionized atoms, the electronic density N per cubic meter decreases and since the conditions of propagation are strongly linked to the ionization of the Ionosphere (N index), the conditions are deteriorated. This phenomenon was also called the Winter Anomaly.

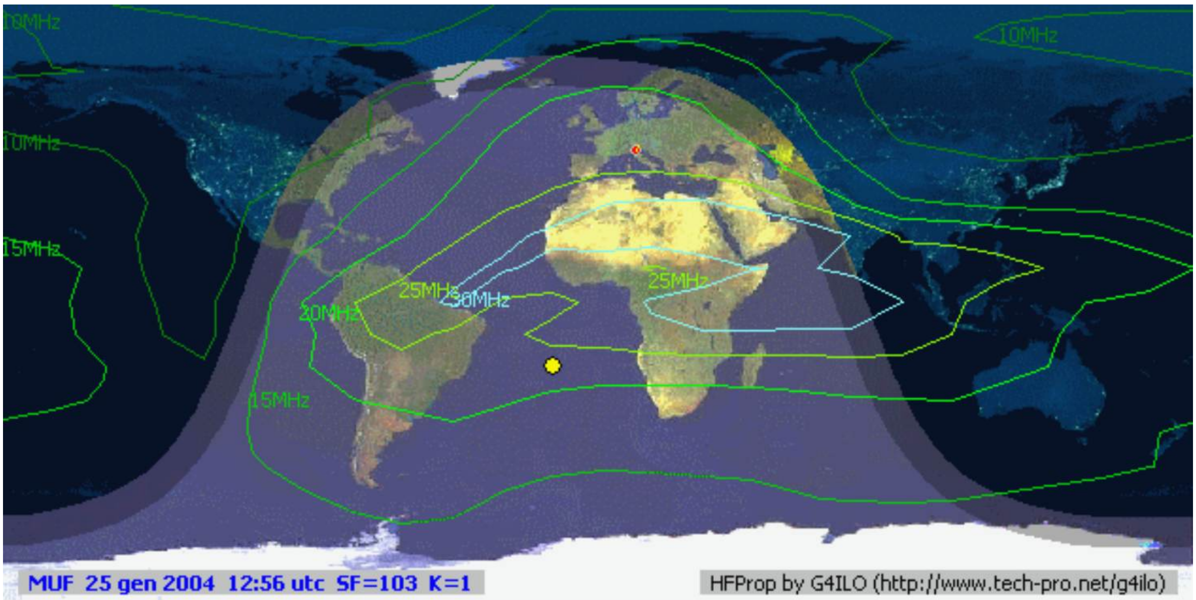
(4) Solar flux

An important indicator of the level of solar activity is the flow of radio emissions from the sun at a wavelength of 10.7 cm (Frequency of 2.8 GHz). The flux has been measured daily since 1947 and is an especially important indicator because it tends to follow changes in the intensity of the sun's ultraviolet radiation affecting the upper atmosphere and ionosphere. We know that

ultraviolet energy is the most important source of ionization of ionospheric layers.

15 meter propagation

General Features



The 15 meter band is influenced by solar activity. During periods of numerous sunspots, long-distance openings occur in daylight hours, extending until late at night. In the afternoon, we have good chances with North America, and towards the evening, opportunities also arise with South America. Not infrequent are openings to the west coast of the United States and Canada, while the Far East, the Pacific, and the Southern Islands are especially notable in the morning. Excellent possibilities for long-distance communication are available by working on the grey line. This phenomenon applies to all bands, but it's more pronounced on the higher bands where signals can be exceptional. In the evening, the twilight belt that passes over our country descends, crossing the entire African continent down to South Africa. Therefore, pointing the directional antenna southward along the grey line can lead to excellent connections with South Africa. This is known as trans-equatorial propagation, which, based on my practical experience, is particularly favorable on the 15 meter band. I will discuss this in detail in the upcoming pages.

Ionospheric path loss

It is not the Earth's surface that introduces the greatest losses in signal propagation, in fact the main cause of loss is in D layer, and this also applies to propagation in 21 Mhz. The signal must pass at least twice within the D region for each ionospheric reflection, in fact it can be noted that during the summer and especially in the months of greatest insolation (July-August) and in the central hours of the day (10:00 – 16:00 local time) due to the high absorption, the propagation is very deteriorated even in 15 meters. This is due not only to the high attenuation, but also to the thermal expansion of the ionosphere which being a gas expands because of solar heating and therefore the electronic density is significantly diluted. In this regard, propagation is better in winter periods and even better in equinox phases, when the absorptions are lower. It is recommended to use the frequencies close to the MUF because they are less absorbed and reflected by the higher layers of the ionosphere.

Trans-equatorial propagation in 15 meters

Trans equatorial propagation (TEP) is an unusual way of propagation of radio waves, first discovered and studied by amateur radio operators. Since then, knowledge about the mechanisms of this type of propagation has increased, thanks to the continuous experimentation of many radio amateurs including several Italians. This mode of propagation is supported by the F2 layer and allows frequencies up to 144 MHz to be reflected from north to south when the maximum normal usable frequency is lower. I have observed several times, especially on the 15 meters, that the beacon that transmit from South Africa, ZS6DN, it can be heard in Italy almost every night, on the grey line and with geomagnetic calm, while for the Beacon that transmits from Kenya, 5Z4B, despite the shorter distance, listening is much more difficult and sporadic. The lengths of the path vary, but they are between 6000 and 9000 kilometers, and both stations should be approximately equidistant from the Equator. In addition,

the path must cross the Equator from North to South or vice versa. Communications have also been made between stations tilted up to 20 degrees on the North-South path, this is possible but rare and in occasional situations.

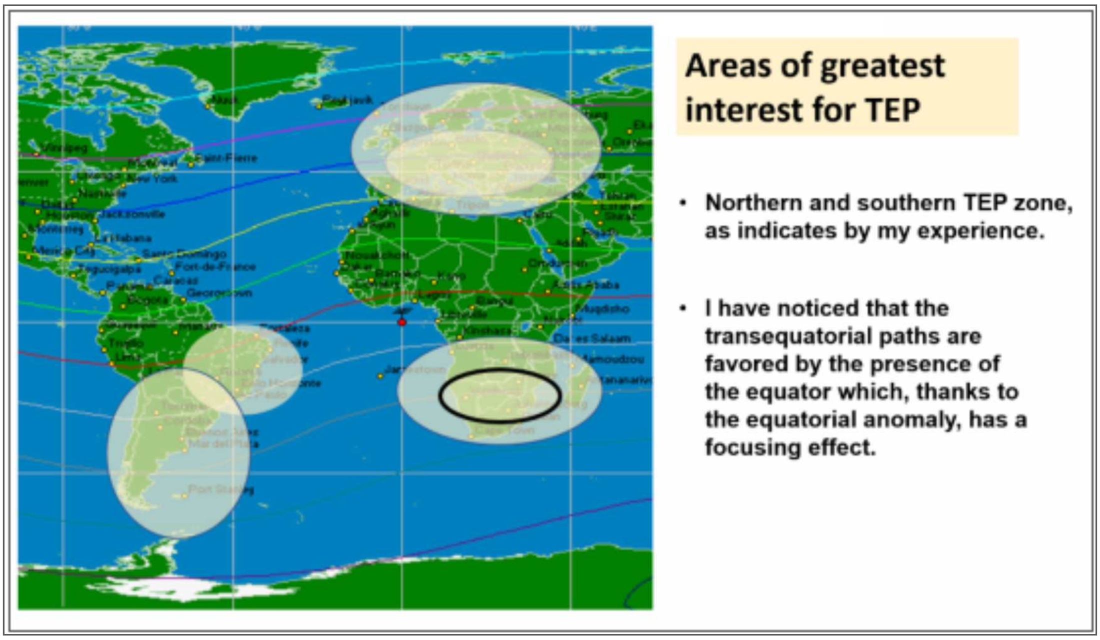


Fig. The map illustrates the principal areas and secondary areas subject to TEP propagation, referred to the European sector. Map created using the DX Atlas software, www.dxatlas.com.

TEP is possible thanks to the equatorial anomaly, which favors an increase of the ionization level in equatorial regions. This allows signals lapping the ionosphere at a correct angle to propagate across the Equator.

Grey line effect

We have repeatedly spoken about the favorable situation when we are near the grey line zone, and this valid also for this frequency. I would like to focus the study about the favorable contribution of the twilight line also for short skip propagation. I have seen several times, how thanks to the grey line, we can work in 15 meters with strong signals from stations along the twilight zone at distances of 400-500 km sometimes even less, while the propagation is poor or even closed for all other directions. This is a focusing affect along the terminator, which is also helped by a very rapid decrease of the attenuation of D region, along the path, also confirmed by the increased summer incidence of this phenomenon. Propagation close as the sun moves to west. At night, the band closes especially in the low phase of the solar cycle. The 15 meters in fact, as well as the 12 and 10 meters, are a predominantly daytime band, although, especially in the high phases of the solar cycle and with geomagnetic quiet, there are long night propagation openings, towards the illuminated part of the globe.

Azimuthal deviations

It is interesting see how often it happens that the signal is received in a different direction than the correct azimuth angle of the correspondent station. Confirmation of this, comes from many cases observed by other radio amateurs because I have confronted myself with them and from the systematic listening of the Beacons of the NCDXF

*(Northern California DX Fo*undation). This propagation anomaly is not a prerogative of the 15 meter band but also takes place on the other frequencies, but I personally observed this anomaly and I studied it only on the highest frequencies, mostly in 17 and 15 meters.

I have catalogued at least three types of deviations:

- **Deviation introduced from auroral oval**
  I have had various confirmations, including from some stations located in Northern Europe, that auroral curtains, are also able to reflect HF signals. Some Norwegian radio amateurs have told me how very often they manage to make connections with stations found to the south, with antennas heading north. It is therefore a question of reflection in the auroral curtain. Similarly, a deviation or curvature can also occur for those waveforms lapping the auroral ovals, the phenomenon can occur independently for the two hemispheres and introduce an error deviation in the order of a few tens of degrees.
- **Deviation due to the effect of the terminator**
  Deviations introduced from the terminator line (grey line), or from the twilight ionosphere. Along the twilight line, the ionospheric plasma is very unstable and constantly evolving due to the pressure of solar radiation. The refractive index varies significantly, and these variations can reflect and therefore divert those signals that lap it.
- **Deviations due to ionospheric abnormalities**
  This phenomenon is rarer and more difficult to catalog, these are deviations due to local anomalies of the ionospheric plasma that the signal may encounter along its path within the ionosphere. These would be real "bubbles" where the electron density is higher than normal (an anomaly of ionospheric plasma very well known for example is sporadic E). Geomagnetic field anomalies, for example, can favor the formation of these anomalies and thicken them in certain geographical areas.

F layer propagation

The F layer is located around 300 kilometers above the earth surface, during the day two distinct ionospheric regions can be distinguished, F1 and F2, these two layers support propagation over greater distances and their contribution even if is more important on the higher bands, begins to be felt even in 20-meters. A few hours after sunset, F1 and F2 merge into F layer.

F layer propagation is limited to wavelengths up to 15 meters, and occasionally 12 meters because to the decrease in cutting frequency. During the day, the F1 layer can reflect radio waves up to wavelengths of about 30 meters, less is difficult. The F2 region is ionized about 1 hour after sunrise and is still ionized until sunset. However, it shows great variability, due to its high sensitivity to solar activity and becomes a daytime band during the lows of the sun's activity. The contribution of the F2 layer is greater during the winter months and during periods of maximum solar activity, where long-distance connections are possible up to wavelengths of 10 meters and even 6 meters. The F2 layer is most accessible in the 20-meter band, when ionization decreases, and long-distance transmissions become possible only on the lower bands. Most of the ionization of the F region is caused by the sun's ultraviolet radiation, and therefore F-layer propagation is better in the higher phases of the solar cycle.

Daytime band

The band of 15 meters is mostly a daytime band, because it requires a high electronic content, this situation is possible only during the hours illuminated by the sun. The distribution of the total electronic content (TEC), within the Ionosphere has a pyramid structure whose vertex is found at the local noon and at a height of about 200 kilometers. The electronic content is progressively reduced with the

height and with the change in insolation related to local time.

Beacons

Considerable help in the study of propagation is given by systematic listening of the beacons. I use the chain managed by the NCDXF Northern California dx Foundation, because it is present on all HF bands from 20 to 10 meters. The beacons are distributed worldwide, and they are active 24 hours a day. The observation of automatic repeaters is useful not only for study reasons, but also to choose the best frequency and to understand where to orient the antenna. The signal transmitted by the beacon is omnidirectional and with progressively decreasing power of 100, 10, 1 and 0.1 Watts. From the observation of beacons, you learn many things about HF propagation. From my geographical position, the signals that arrive with more regularity are those of CS3B, 4X6TU and OH2B from Finland. The beacon in Finland, however, only arrives if the geomagnetic field is quiet. The Japanese beacon, JA2IGY is particularly useful for testing long-distance propagation, while the VE8AT beacon, in the Canadian Arctic is important for trans-polar propagation and at the same time difficult to hear.

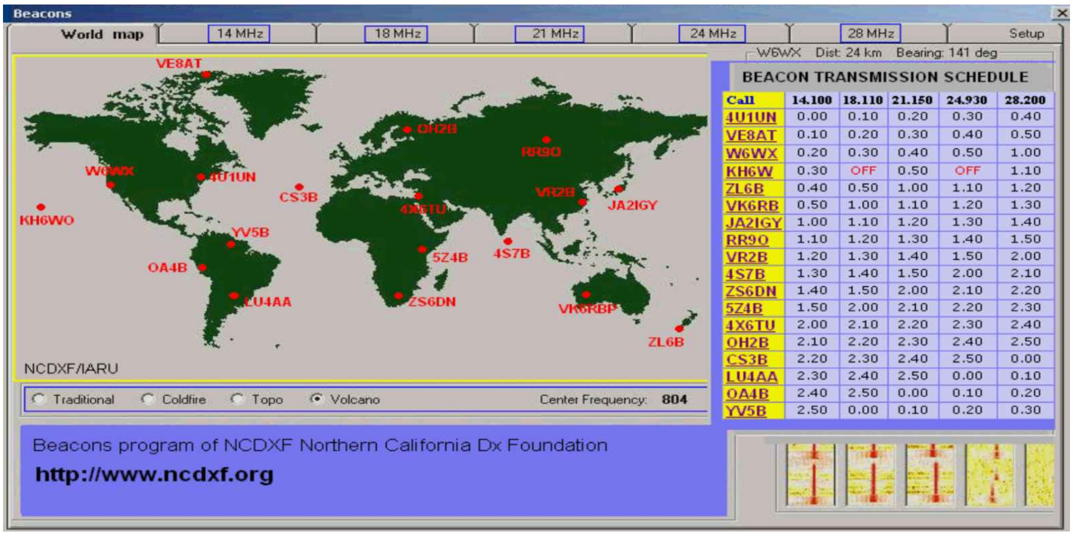


Fig. The image shows the map with the world distribution of NCDXF beacons.

Geomagnetic field

Even for the 15 meter band, the quality of propagation is significantly influenced by the conditions of the geomagnetic field. A quiet geomagnetic field is very often an indicator of good propagation. For good propagation conditions, It is not enough to have high ionospheric ionization indices (deductible from solar flux values or from the number of sunspots), but you also need a low index of the geomagnetic field (deductible from K or A index), a K index that goes from 2 to 3, is enough to trigger a lapse of propagation.

Indici geomagnetici e propagazione HF **(K index/ A index)**

indice K	stato	indice A	Campo geomagnetico	Propagazione
1		4	Calmo	eccellente
2		7	Calmo	eccellente
3		16	Perturbato	buona
4		27	Perturbato	normale
5		48	Agitato	mediocre
6		80	Agitato	mediocre
7		140	Agitato	mediocre
8		240	Fortemente agitato	cattiva
9		400	Fortemente agitato	cattiva

As an indication, I give a summary table with some information about propagation conditions correlated with geomagnetic index. To try to make some predictions it is always important to relate the values of K and A with the value of the daily solar flux (SFI Solar flux) and for this purpose I have reconstructed the following purely indicative table:

- Index K <1 (Index A<4) – Solar flow SFI 150 to 200: Excellent propagation
- Index K 2 to 3 (Index A from 7 to 16) – Solar flow SFI 120 to 150: Good propagation
- Index K >3 (Index A > 27) – Solar flow SFI 90 to 120: Normal propagation
- With K>5 (index A > 60 indices and solar flow SFI values < 90: Poor propagation

Seasonal and daily variations

Dependence on solar activity is important, because we know, the best results are when the solar flux is high, in the high phase of solar cycle, however, taking advantage from the best moments, you can have good propagation openings even in the lower phase of the cycle. The best moments as always following the twilight zone, in the morning for example, about an hour after sunrise, the conditions are good towards the Far East and Japan, while in the evening you can work all South Africa, taking advantage from the propagation along the terminator. The beacon that transmits from Pretoria, ZS6DN, is audible in Italy with good regularity, even in the low periods of the cycle. Due to summer depression, propagation is qualitatively better in the winter period.

A summary of the situation is as follows:

- **Low phase of the solar cycle:** The band opens after sunrise and closes just after sunset. The propagation is open only during the day and frequent short skip openings. Dx connections are only possible at the best times, when the value of the solar flux rises beyond certain limits (even when the number of spots is low, it is still an average, and there may be days when the level of spots improves) and the geomagnetic field is quiet.
  In principle, however, the number of opening hours decreases as the cycle decreases.
- **High phase of the solar cycle**: The conditions are good even before sunrise and for several hours even after sunset. During the best moments, the band can be open even at night. In periods of high solar activity, 15 meters may be the best band for DX, especially at our latitudes, also because absorption is low near the equator and the tropical belt, but this aspect can deteriorate communications for those connections that cross the equator and come into contact with the areas of maximum solar radiation.

Notes:

1) D Region
It is the lowest part of the ionosphere between 70 and 90 km above altitude and has the lowest ionization density, it is present only in the sunlit part. It has the negative effect of attenuate the waves that pass through it especially those with lower frequency. At dusk, rapid degradation of layer D occurs, by recombination, positively influencing the propagation conditions of electromagnetic waves.

2) Equatorial anomaly
One of the most interesting features of the tropical ionosphere is the equatorial anomaly and consists in the fact that in areas between 20 and 30 degrees, north and south of the geomagnetic equator, the influence of the sun's zenith distance on the electronic concentration of the F2 layer is noticeably different from what is expected. Solar radiation, especially ultraviolet rays, causes rarefied air to ionize and therefore we find a large electronic density in the tropical region and a high number of free electrons caused by the solar wind that align the electrons along the force lines of the Earth's magnetic field. Cigar form masses are formed aligned with the field. If solar activity is high, these cigar form masses have a higher ionization density than the ordinary F-layer and behave like the walls of a giant wave guide capable of conveying for about 4000 km. (straddling the geomagnetic equator) the signals. The discontinuities present at the edges allow the wave trains to enter and exit the guide.

Frequency Doppler in HF 21 MHZ

During a local digital QSO using the JT65A mode, I noticed that I received a second trace in addition to the main one, and it exhibited frequency shifts. A signal that undergoes frequency shifting is invariably associated with movement. The frequency difference of the first trace is approximately -20 Hz, which might be indicative of an airplane reflection. Additionally, there is a

second trace exhibiting double Doppler shift, approximately -40 Hz. Both traces exhibit a spreading effect known as Doppler spread. In total, I received three traces, including the main one. Interestingly, the secondary traces had a higher intensity than the main trace.

Fig. The QSO with IZ3BUR in 15 meters at distance of about 50
kilometers.
Map created using the DX Atlas software, www.dxatlas.com.

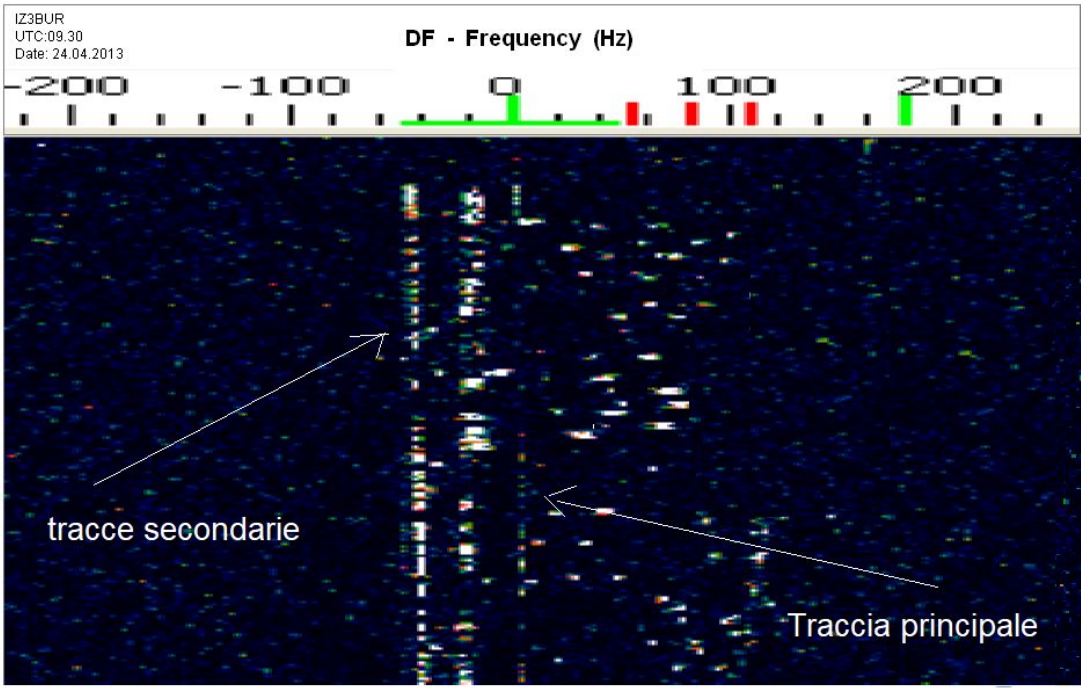


Fig The main trace is the faintest one on the right of the spectrum. At the left, there are two secondary tracks with doppler of - 20 Hz and of - 40 Hz. Secondary tracks also show a spread doppler effect.

10 meter propagation

General features

Short-distance connections become feasible by capitalizing on the moderate curvature of waves due to the troposphere, enabling connections beyond the optical range. Particularly in the summer, connections within a radius of 2000 – 2200 km are attainable through reflections caused by the sporadic E layer. During periods of heightened solar activity and daylight hours, exceptional long-distance communications are achievable, even with low power. The intense ionization of the F layer facilitates the reflection of waves at 28 MHz and beyond. As solar activity diminishes, the opening times progressively shorten. Attenuation from the D layer is utterly negligible, and atmospheric noise remains minimal, facilitating the reception of even the faintest signals. Short-skip openings are quite frequent, often attributable to the sporadic E layer. On both 28 MHz and 50 MHz, working with weak signals across distances ranging from 1500 to 4000 km through ionospheric diffusion (Ionoscatter) is possible. These signals exhibit the characteristic of being extremely faint and accompanied by a subtle and gradual fading, although the absence of atmospheric noise enhances their reception. During optimal periods, it becomes feasible to establish worldwide connections even with low power, producing excellent signals. The position of the 10-meter band at the upper limit of the HF spectrum, like the 160-meter band at the opposite end, renders interpretation and prediction challenging. This positioning also exposes it to fluctuating conditions, as propagation can undergo significant and abrupt fluctuations in response to variations in geophysical indices.

TEC (Total Electron Content)

The differences in TEC, total electronic content, depends by latitude and local time. The concentration is maximum

in the central hours of the day with a greater concentration in the tropical belt, these electronic concentrations, determine the level of ionization of the layers. In 10 meters TEC has greater importance for long distance communication than the other high frequencies of HF.

Absorption

One of the advantages of this band is the low level of ionospheric absorption. We know that for short waves, the attenuation introduced by the D region is the most important form of absorption, but the absorption intensity is inversely proportional to the square of the frequency, which means that for frequencies close to 30 MHz, attenuation begins to become less and less important and allows connections even at a great distance, with low power, the limit is that the ionosphere is not always able to support propagation.

Sporadic E

Towards the end of Spring and the beginning of summer, communications traffic on the 10 meter band increases and strong signals begin to arrive that can disappear quickly or they can last all day and they come from the same geographical direction or arrive from various directions but from distances almost never exceeding 2000 km. This happens even if solar activity is low. This is sporadic E propagation supported by large highly ionized zones in E layer of the ionosphere whose origin is uncertain but due to the action of strong ionospheric winds that amass metal ions present in the ionosphere in dense plasma clouds capable of successfully sending HF signals back to earth. Sometimes, the ionization density becomes so high that frequencies of 144 MHz can also be successfully reflected to Earth. These ionizations are located at a height of about 100 km, limiting the skip to around 2000 km. Double skips are also possible, although due to the irregular nature of ionizations, these events are rare. The optimal times to observe the Es (sporadic E-layer propagation) on the 10 meters band are from 0900 to

1100 and 1900 to 2300 local time. However, such events can occur at any time of the day. The typical period for this phenomenon is from May to August, with a secondary winter recovery period in December and January. When the skip becomes short, indicating dense ionization, the ionization itself is very concentrated. During periods when 10 meters are open for Es propagation, the 12 and 15 meters bands are also usually open, and often the 17 and 20 meters bands are open as well, albeit with shorter skip distances. The skip distance decreases as the frequency decreases, as the signal gets progressively refracted to lower altitudes due to the reduction in frequency

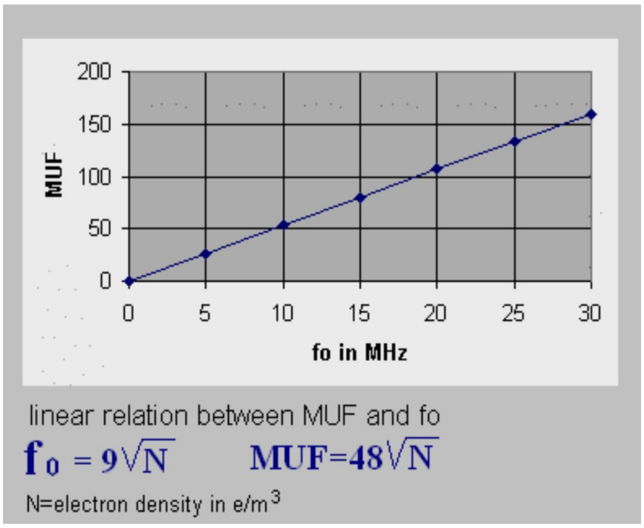


Fig.: The diagram above at left, shows the linear relationship between the MUF and the critical frequency fo ***(1****), that derives from the formula written below the graph. Experience, however, shows that the formation of the sporadic E does not fully follow this linear relationship, but this discussion is important for understanding the basic principles.*

Favorable directions

From various observations and experiments, seem to be favorable and repetitive directions in sporadic E opening, but that is not all. The hypothesis, which does not yet have a scientific basis, is that the directions of the QSO follows some possible geomagnetic anomalies present on the Earth's crust and concentrated in some geographical

areas, anomalies that could concentrate the ionospheric clouds more often in certain areas.

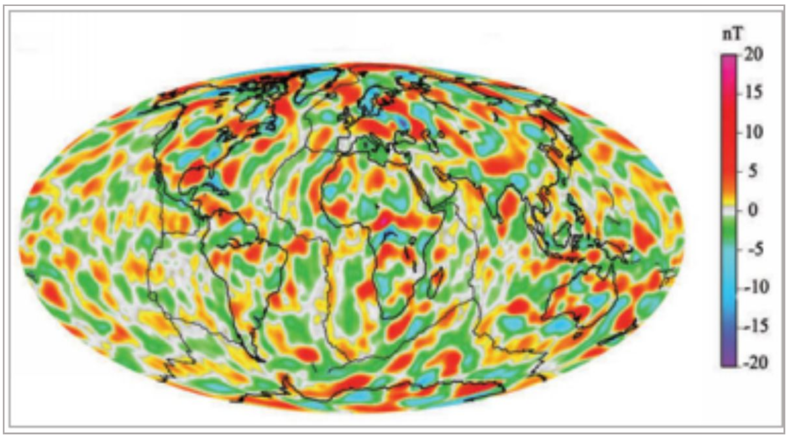


Fig. Global map of geomagnetic anomalies: Some areas align with recurrent favorable openings in specific directions. As an example, there is a region situated above Hungary, recognized by OM active on the 144 MHz band, responsible for propagation openings at 144 MHz, known as FAI (Field Aligned Irregularities). (Lithospheric magnetic abnormalities): This modeled image illustrates variations in Earth's magnetic field caused by scientific satellites like Magsat. Units are measured in nanoteslas (nT). The color scale indicates areas with positive and negative magnetic fields. (Image credit: Wikipedia)

Propagation and solar cycle

The propagation in the 10-meter band is influenced by the sun's approximately one-decade cycle. Apart from sporadic E propagation, DX connections in the 10-meter band are facilitated by the upper layers of the ionosphere, primarily the F region, which becomes ionized due to the intensity of solar radiation, often measured as the 10.7 cm radio flux. The behavior of this band is more susceptible to the intensity of the solar cycle compared to all other HF frequencies. During periods of low solar activity, the band can appear closed, and DX activity tends to concentrate during the upper phase of the solar cycle. Even during the low phase of the solar cycle, there are sporadic openings caused by temporary ionizations of the ionospheric layers. Some of these occurrences result from ionized particles forming as random ionized clouds in the upper atmosphere, including sporadic E events and other similar phenomena. In the early 1980s, the significant eruption of Mount St. Helens improved propagation levels for several months. Similarly, the Russian nuclear accident in the mid-1980s also led to a notable improvement in propagation. At times, propagation can unexpectedly improve without a clear explanation. This characteristic makes the 10-meter band one of the most challenging frequencies to interpret, while simultaneously adding to its fascination. The scarcity of traffic and stations using the 10-meter band is such that the frequency seems closed more frequently than it is.

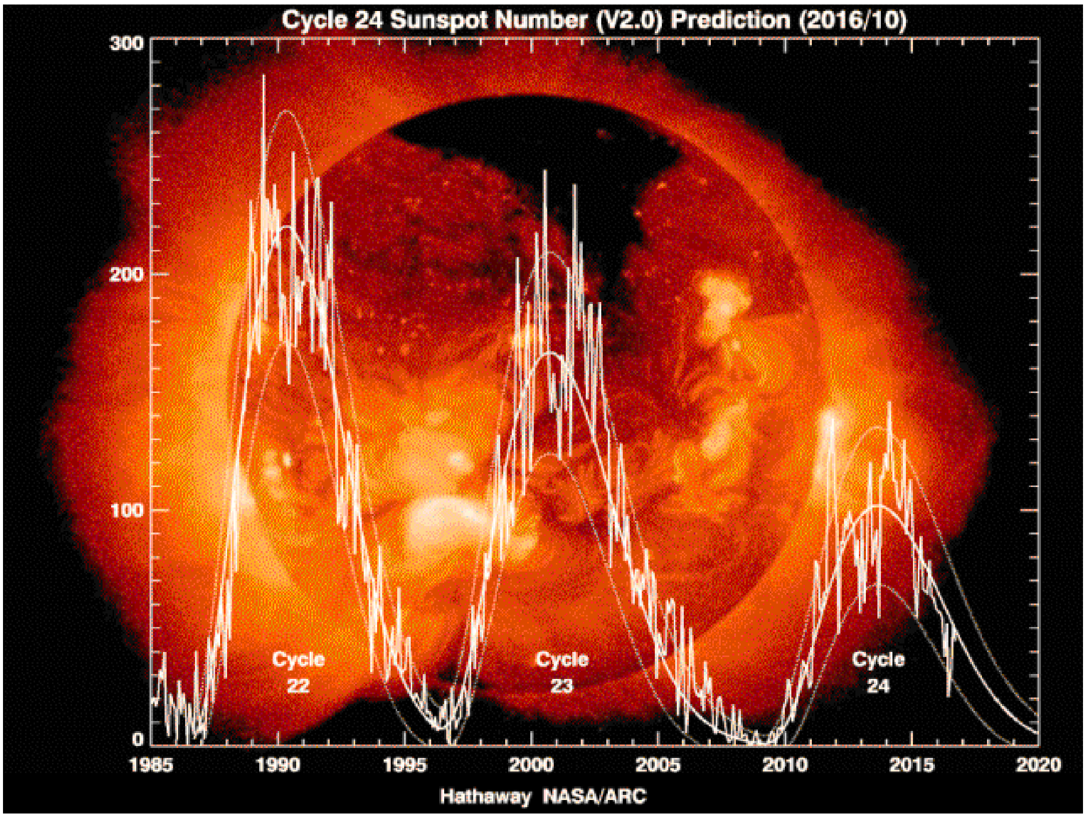


Fig. Solar cycles. (Image Wikipedia public domain – Author: David Hathaway, NASA, Marshall Space Flight Center).

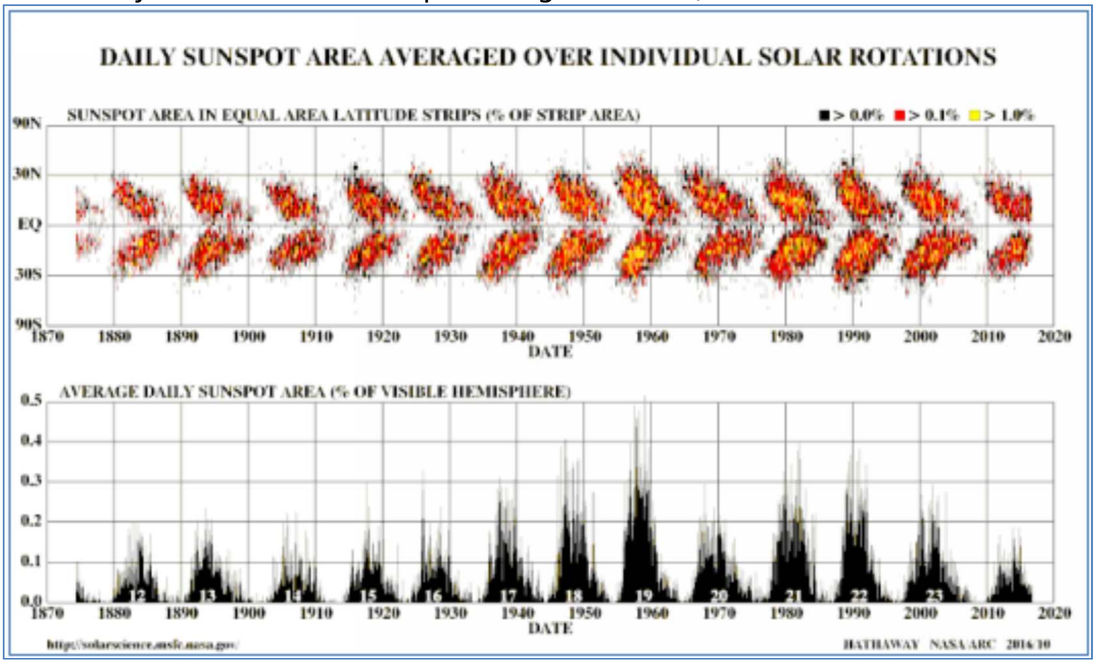


Fig. Daily sunspot area averaged over individual solar rotations. This is colloquially known as the "Butterfly Diagram". Detailed observations of sunspots have been obtained by the Royal Greenwich Observatory since 1874. These observations include information on the sizes and positions of sunspots as well as their numbers. These data

show that sunspots do not appear at random over the surface of the sun but are concentrated in two latitude bands on either side of the equator. A butterfly diagram (updated monthly) showing the positions of the spots for each rotation of the sun since May 1874 shows that these bands first form at mid-latitudes, widen, and then move toward the equator as each cycle progresses. (Image Wikipedia public domain – Author: David Hathaway, NASA, Marshall Space Flight Center).

Noise

The noise is negligible, the band is the quietest of the HF. The atmospheric noise becomes negligible. The most important form of noise is artificial noise from human activities, followed by galactic noise that is not heard since it is confused with the background noise of the receiver. In general, contrary to the low HF bands, the highest noise levels are in the middle hours of the day but in 10 meters, noise is never a problem to face.

Ionoscatter (ionospheric diffusion)

Ionoscatter is the spread of radio waves in the ionosphere caused by turbulence or irregularities in electronic distribution causing variations in the refractive index, this happens at the height of D region, between 70 and 90 km above the ground.

Propagation for ionoscatter is theoretically possible throughout the 24 hours, since the irregularities we have just talked about, are always present in the structure of the ionosphere, and it turns out to be little dependent on space weather, however the best conditions should be in the middle hours of the day, when D layer has maximum ionization. For the same reason, there seems to be a higher incidence in active sun periods. The characteristic of the signal supported by ionoscatter propagation is to be very weak, with slow fading, in the order of a few minutes, and very often subject to flutter fading. The skip distance can range from 800 to 2200 km, so there is a large shade area, not covered by ionospheric diffusion. Due to the considerable dispersion of the signal, efficient directional

antennas and high power are needed, at least a few hundred watts, consider, in this regard, that even if the directive antenna has a good gain, the width of the beam transmitted is not less narrow than 60° and this means that the reflection surface a few hundred kilometers has a huge width, with the consequence , on the one hand a large dispersion, and on the other, we strongly increases the possibility of finding ionospheric anomalies. Within such a large ionospheric volume, there are multiple irregularities that in addition supporting propagation as a result that the scatter effect, introduce continuous variations in polarization and phase. This is the explanation of the characteristic flutter fading of the signal.

Tropospheric propagation

The contribution of tropospheric propagation in 10 meter band, takes on an important significance and is greater than in the other bands of the HF spectrum. Connections of a few hundred kilometers are possible using tropospheric refraction, as is the case for example for the 2 meters VHF band, however the distances reachable are less than 2 meters since the contribution of tropospheric propagation is less, due to the higher wavelength and the difficulty of obtaining antennas with high standard gain, like the long Yagi for 2 meters.

Backscatter

Normally two nearby stations cannot listen to each other because to the large area of silence (shadow zone) that surrounds them. In 10 meters this area of silence, (except for tropospheric propagation), can be estimated at around 200-300 km. In the low bands of the HF, this distance is much shorter or even does not exist. In some cases, when ionosphere conditions allow, two stations within the shadow zone can be heard because of back scatter or side-scatter propagation. When the frequency of the transmitted signal is near the limit of the MUF, signal is reflected to the ground in E region or F region, but part of

this emission is reflected into an area shared by both stations, and within the theoretical shadow zone. The signal appears very modulated and easily recognizable since it is free of evanescence but characterized by a strong echo effect. The use of directional antennas accentuates the phenomenon that appears concentrated in the bands above 18 MHz

F2 layer propagation

During the summer, even in periods of low solar activity, it is likely that the MUF rise above 30 MHz in a range that is about a thousand kilometers south of Italy. It is a good area for various reflections supported by the Ionosphere at lower latitudes, confirming the always valid rule that propagation has important geographical variations. In this regard, I would like to introduce a concept on the angle of irradiation of the antenna, which is particularly important for the DX on the most critical path, such as the Trans-Polar Circuits to Alaska and Northern Canada, may seem trivial, but the presence of more or less high mountains drastically reduces the possibility of making the connection and paradoxically, in this case a low irradiation angle antenna can penalize rather than favor the DX. During solar cycle peaks, the F2 region can extend the MUF up to 60 MHz, allowing openings to the Americas, Africa and Oceania for those right-hand stations working at or below these frequencies. The activity via F2 is large in high solar activity since the general rule applies the relationship that as the activity of the sun increases, the MUF F2 increases proportionally. F2 propagation in VHF is quite unlikely in periods of low solar activity and tends to have peaks in the spring and autumn months, focusing in the hours of the day as it is a propagation that directly depends by the radiation of the sun and therefore suffers from the geographical position understood as latitude.

Field example

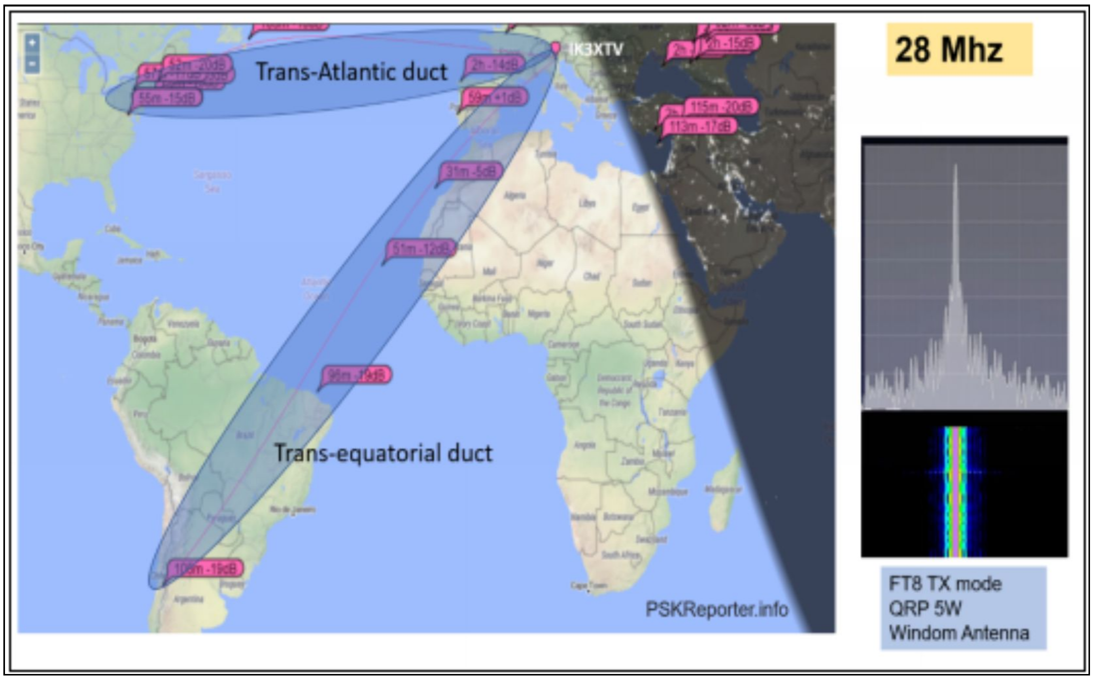
As an example, I reported below the data relating to an exceptional propagation opening in 10 meter band of

October 23, 2004, from 13 UTC and throughout the afternoon, the band closed at 16:30 UTC (immediately after sunset).
Propagation path was open to east-west direction (USA East coast, Chile and Argentina) with excellent signals. The geomagnetic indices and the graph of the ionosonde of the National Institute of Geophysics and Volcanology of Rome, from which if it deduces an MUF climbed above 32 MHz, are reported below:

<u>Solar and geomagnetic indices of 23/10/2004</u>
Sunspots: **134** as of 10/22/2004: Flux: **123** | Ap: **5** | Kp: **1 (05 nT)**
Solar Wind: **352 km/s** at **6.8 protons/cm.** On 2004 Oct 23 1438Z: Bz: 3.5 nT
Bx: 4.6 nT | By: -1.9 nT | Total: 6.1 nT - Aurora Activity Level was 3 at 1202 UTC

Duct propagation in 28 MHz (FT8 experiments)

I have done several experiments with low power transmissions (5 watts) in FT8 digital mode and I have noticed that there seem to be some preferential ducts. The mechanism is always the same, I talk about it extensively in this book. These are the ionospheric waveguides, which appear to form in certain directions. The trans-equatorial paths are favored, both north and south, towards South Africa, but even better towards South America, in an oblique trans-equatorial path. On 10 meters, these trans-equatorial paths work very well, even with very low power and wire antenna systems. However, these waveguides also work in other directions. I got the idea of a selective ionosphere that creates certain favorable waveguides that are still under investigation. The following map, worked with Psk Reporter, one of the experiments I conducted with FT8 and which shows quite well the behavior of the ionosphere. Please see the geodetic line, which connects for example IK3XTV with the Canary Islands, Cape Verde, northern Brazil and down to Chile, (Trans-equatorial duct). All these stations received my 5W FT8 signal within about 1.5 hours. Or the other geodetic line that connects IK3XTV with Newfoundland, up to New England in the USA, (Trans-Atlantic duct). The width of the waveguide could be indicatively between 500 and 1000 kilometers. Experiments conducted in November and December 2022.



Why use low power?

To observe the behavior of the ionosphere, according to my opinion, it is preferable to use low power because, in this way, it is like observing the phenomenon with a magnifying glass. Using high power is equivalent to observing the phenomenon from afar, making it difficult to see precisely what is happening. Galileo said*: "Measure what is measurable and make measurable what is not."*

Notes:

1-**fo critical frequency**: The critical frequency is that frequency with vertical incidence that an ionospheric layer (E or F) can reflect towards the ground.

Grey line in 10 meters

One of the amateur radio's best friends is grey line. This is also true in 10 meter band. If you have small antennas and little power, you can always count on this trusted friend. It's often about waiting for the right moment. I talk extensively about the grey line in this book and I have done many experiments using mostly low power. In December 2022, under winter ionospheric conditions, I set up my SDR transceiver transmitting in FT8 (digital mode) with an extremely low power of 0,5 Watt and wire Windom antenna The result is shown in the map below, where you can see how my FT8 signal was received by the stations aligned along the grey line. I also tried to reduce the power by 10dB, so I transmitted with 0,05 Watt, but the signal did not arrive. Not even the grey line can work miracles.

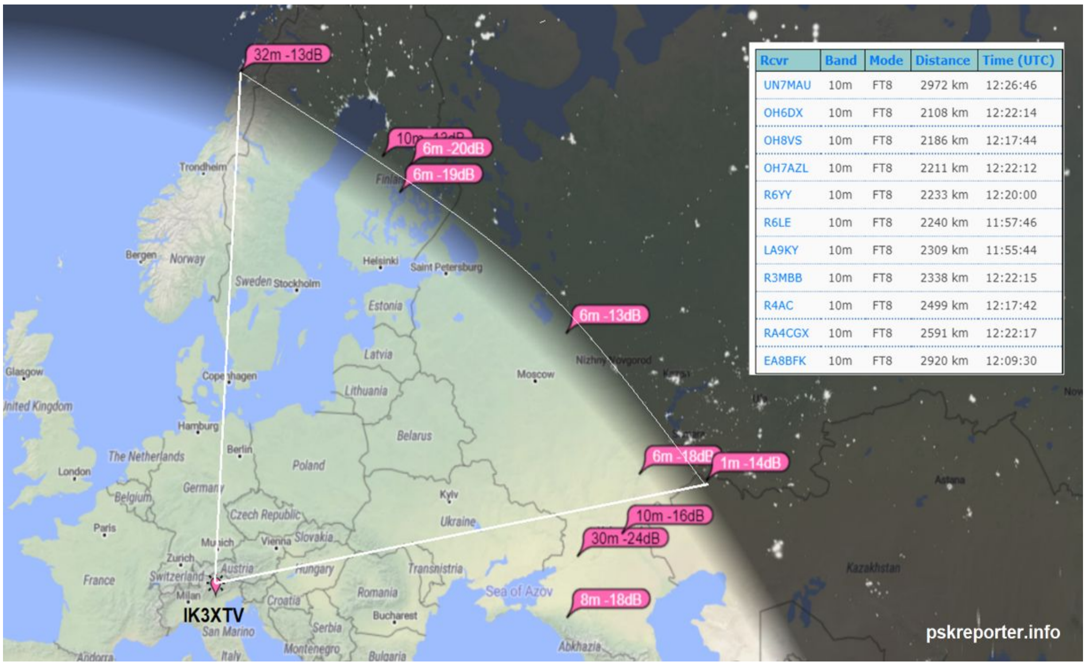


Fig. Pskreporter map showing stations that received my FT8 signal transmitted with 0,5 Watt and wire Windom

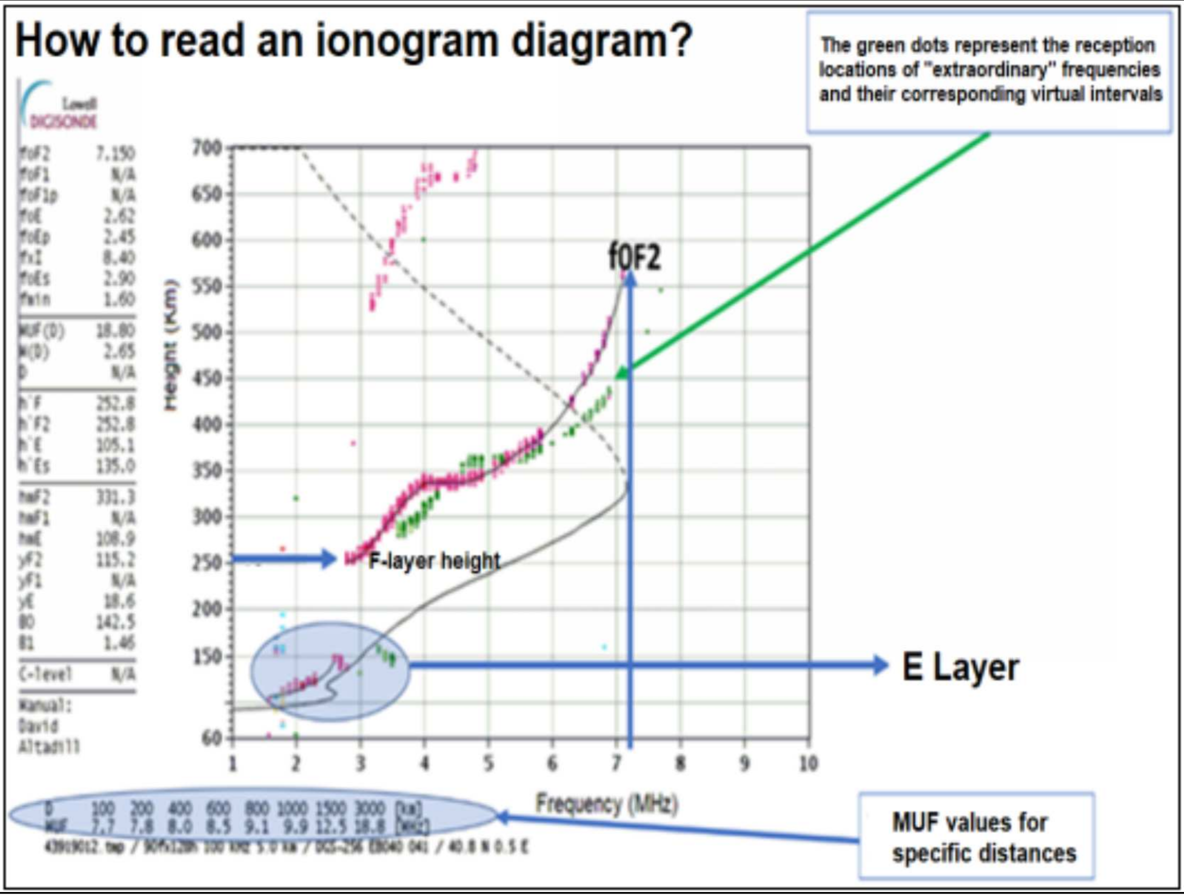
antenna The stations are all along the grey line, from Kazakhstan in Asia to Scandinavia. The skip is between 2000 and 3000 kilometers. Test date: December 10, 2022. Credits:pskreporter.info.

The MUF calculated from a vertical ionogram assumes that the reflection point on the ionosphere is above the ionosonde. The MUF can be defined by knowing the link distance and the critical frequency f0. Some ionosondes provide MUF values for specific distances. For example: 100-200-400-600-800-1000-2000-3000 Km, and a corresponding MUF value is indicated for each of these distances. As a convention, the MUF at 3000 Km is often provided.

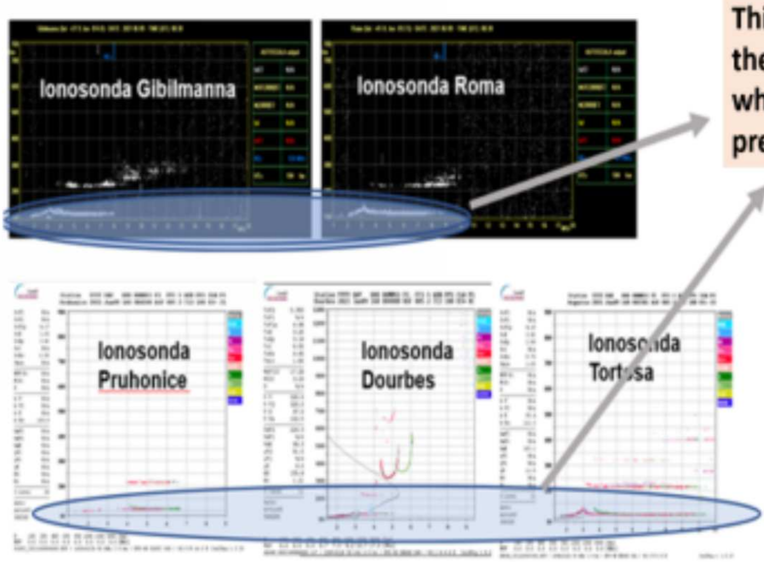
$$F(MUF) = foF2 * \sec \phi$$

From a practical standpoint, it is advisable to refer to the FOT, which stands for the Optimum Working Frequency. It is the frequency that allows radio communication on 90% of days and is approximately calculated as 85% of the MUF.

FOT= 0,85 * MUF



The ionosonde graphs in the locations shown on the map were recorded on the morning of June 9, 2021.



This is the line that indicates the critical frequency F0Es, which represents the presence of sporadic E

In all these 5 ionosondes, we find the line indicating the presence of Es.

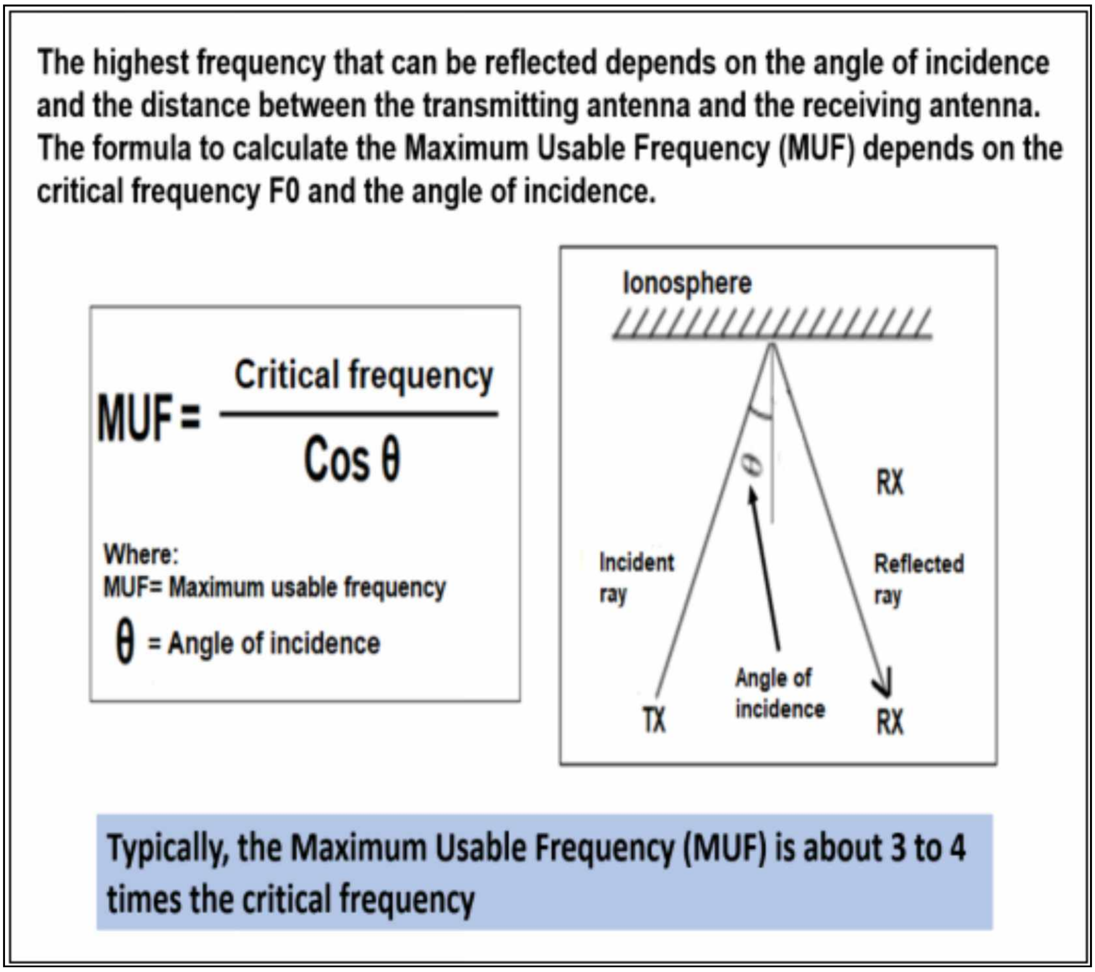
Extended sporadic E

During the summer months and under favorable conditions, extended sporadic E (Es) propagation can occur, covering areas of several million square kilometers. An example of this is the event I observed on the morning of June 9, 2021. Even early in the morning, the critical frequency level (F0Es) rose above 9 MHz, as reported by the ionosondes shown on the map of Europe on the left. I detected Es openings with short skip distances ranging from 7 to 50 MHz, and the skip distance increased as the frequency increased.

Medium skips
40 metri range 50-200 km
20 metri range 200-600 Km
15 metri range 400-1000 Km
10 metri range 500-1500 Km

Due to a law of refraction of optics, the longest waves undergo a greater curvature towards the earth, as they pass through the intermediate layers of the ionosphere and troposphere. This is why the skips are gradually shorter as the frequency used decreases.

Sporadic E cloud covering most of Europe on the morning of June 9, 2021



5Z4B beacon: Reception experiments in 28 MHz

In the solar minimum phase, the band of 10 meters is always closed especially for long distances. Band

Openings are quite rare, except on rare occasions. The experiments conducted by monitoring the beacons of NCDX Foundation, with Faros software, highlights the possibility of good and regular openings even on DX path. In this case we focus on receiving the 5Z4B beacon from Nairobi – Kenya that can be heard in Italy. Although with a brief time window, but with good regularity. During the observation period, no other beacon in the NCDXF chain is audible at 28,200 KHz except in sporadic cases the beacon from Israel, 4X6TU.

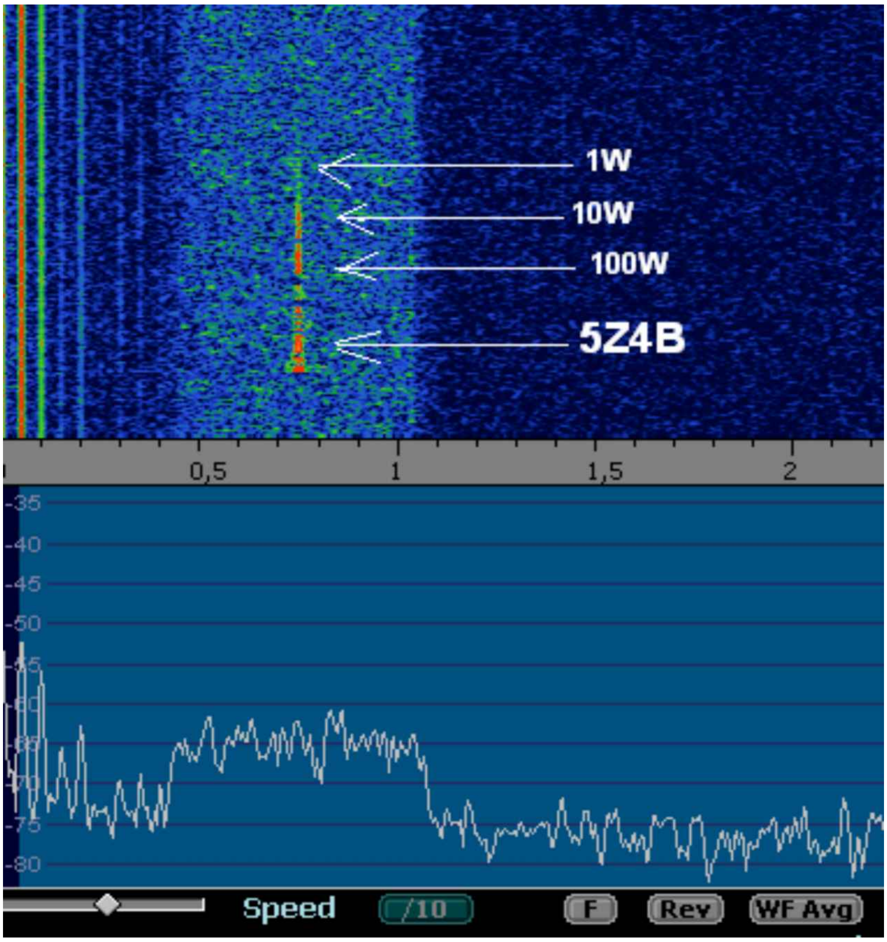


Fig. Spectral analysis of the beacon with WINRAD software. There are clearly visible the CW lines transmitted sequentially with decreasing power. Experiment of May 1, 2009.

MUF

The experimentation with Faros shows a similar result with the MUF diagram elaborated with Voacap (diagram below). When the beacon is audible in 28 MHz, it is audible even in all other bands. So, for a brief period the MUF goes up to 28 MHz and more. Some days the propagation window is short, about 10-15 minutes, this is the most common situation. Rarely, the opening window extends beyond 40 -50 minutes. This only happens on the most favorable days. In some cases, two opening windows have been recorded because the path often opens also on the grey line (sunset) in the beacon location and in rare cases also on the grey line (sunset) in Italy. The observation period is within an interval of 2 months (May and June 2009).

Conditions

During the observation period the geomagnetic conditions had always been quiet. With number of sunspots around zero. In addition, the best openings (both as signal quality and duration) occur with good weather conditions (high pressure on a large scale along the path).

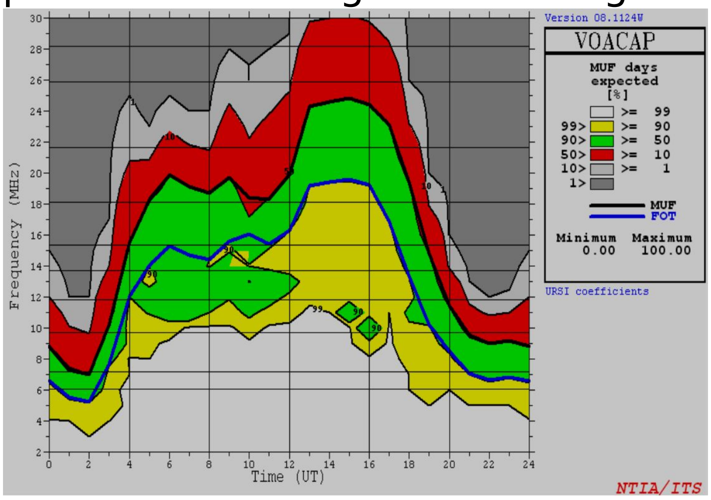


Fig. MUF graph developed with Voacap software.

Meteor Scatter experiments in 10 meters

I have conducted several meteor scatter QSOs on 2 meters, and this mode of propagation has always fascinated me. You need to wait for a meteorite to pass through the sky and search for reflections at a height of about 100 kilometers in the ionized trail left by micro-meteors as they enter the Earth's atmosphere. This requires a combination of luck and perseverance, and the process takes some time to complete a QSO. However, the sense of satisfaction in the end is profound. The bands most used by radio amateurs for this type of activity are 6 meters and 2 meters. The emergence of the new digital age and the proliferation of various meteor scatter software have made meteor scatter propagation even more interesting, expanding interest and expertise in VHF. For a long time, I pondered how meteor scatter might work on the 10 meters HF band. Consequently, I decided to conduct experiments on the 10 meters band. The results were quite promising, although I faced some challenges in finding other interested correspondents. I located them by arranging skeds on the popular ON4KST chat, a platform dedicated to VHF and above communications. Eventually, I managed to engage in QSOs and received the pings from several stations. The digital mode I opted for is ISCAT, which is included in Joe Taylor's (K1JT) WSJT software package. This mode provides an alternative means of utilizing the 10-meter band, especially during periods of minimal solar activity.

ISCAT is a fast protocol designed to obtain the best performance in short reflections on ionized meteor trails. This mode uses timed sequences with a selectable duration of 5, 10, 15 or 30 seconds. I used sequences of 30 seconds. The messages, i.e., the names and the

reception S/N, are transmitted repeatedly and at high speed to make the most of the scatter.

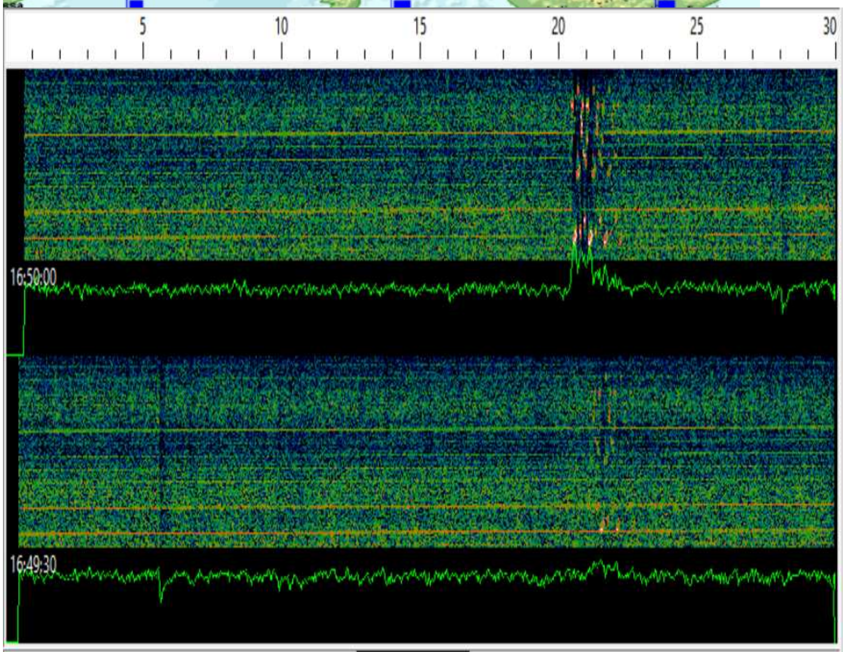


Fig. Image on the right shows a burst meteor scatter of about 2 seconds, received during qso with ON6NL in date 12/12/2017 16.50 UTC. Fig. The image on the left is the map of the *QSO with ON6NL (skip 745 km) and with DK5KMA (skip 531 km). I used only 100 watts of TX power and a simple 2 elements Yagi. Map created using the DX Atlas software, www.dxatlas.com.*

Distances and angles of irradiation.
MS reflections take place at the height of about 100 km. Theoretically, for an irradiation angle < 10 degrees, a skip of more than 1100 km is obtained. The theoretical maximum limit is 2400 km, with an irradiation angle close to 0 degrees. In 10 meters there are few stations equipped with antennas capable of radiating at angles below 10 degrees. Very often the antennas used have very wide irradiation angles and this implies that the skip obtainable is short. My QSOs have a skip around 500/700 kilometers. The low efficiency of the antennas (compared to VHF) is partly compensated by the received power which is directly proportional to the square of the wavelength (equation of the power received taken from the RECOMMENDATION ITU-R P.843-1- Communication by Meteor-Burst Propagation). In 28 and 50 MHz, an active meteor can sustain propagation from 30 seconds up to a few minutes. In the 2 meters, the same meteor, would allow communication only from a few seconds up to a maximum of one minute.

D.A.R.C. 10 meters contest of 14/01/2018.
During the DARC 10 meters contest in 2018, I listened in 28 MHz band, and propagation was closed. But I received only a few clips of calls that I attribute to meteor reflections. That reflections were too short in duration to

be Air scatter (Reflection from airplane). I recorded with the HDSDR panadapter some examples of reflected signal, as in figure below, where you can see about 150 KHz of bandwidth. You can also see the effects of the progressive evanescence of the signal caused by the dispersion of the ionized wake. (Exponential decay of signal strength).

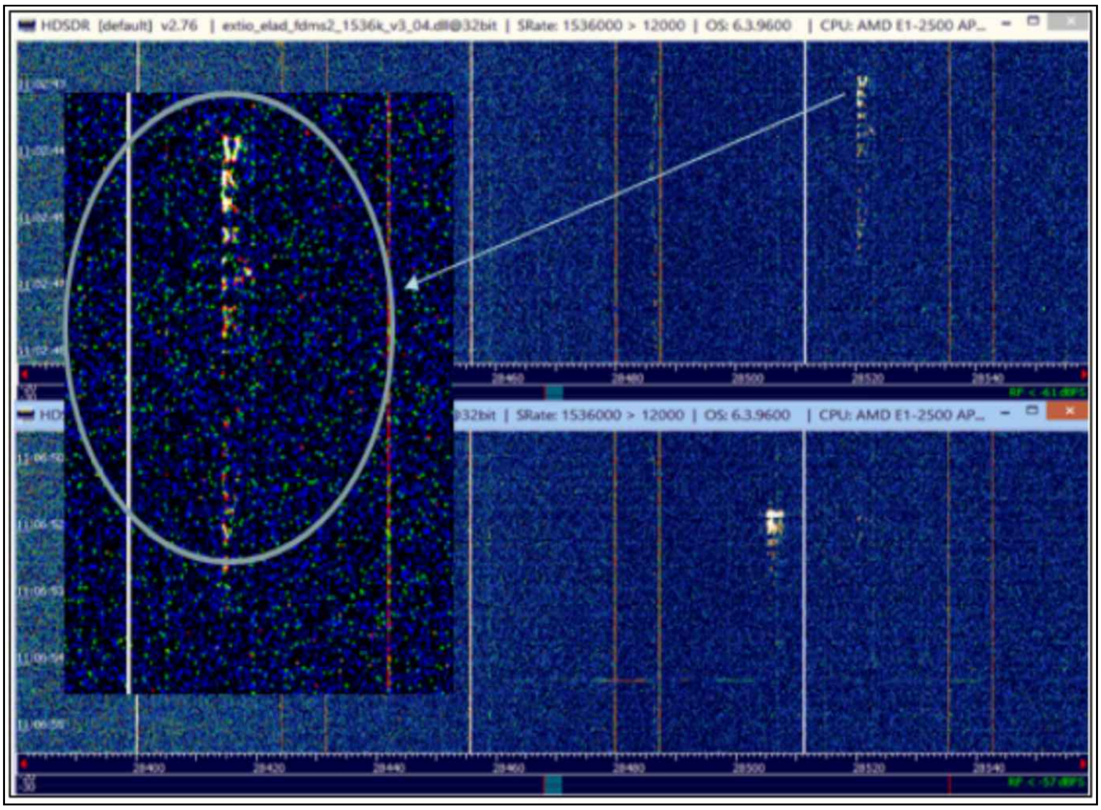


Fig. I captured a couple of screen shots of the waterfall (at two different times, upper and lower part of the figure) of random meteor scatter reflections received during the DARC 10 meters contest of January 14, 2018. The band was completely closed but it was possible to hear from time to time, callsign or piece of call, from German stations calling CQ contest and looking for connections. The two signals you see, are reflections of transmissions in SSB, lasting up to two seconds.

Propagation in the WARC bands

I have always been fond of the WARC bands. In the upcoming pages, I would like to provide some insights into the propagation characteristics of the 30, 17, and 12 meter bands. These bands were acquired for amateur service during the 1979 WARC (World Administrative Radio Conference), making them the most recent additions.

17 meter band propagation

General features

It is a band that can give great satisfaction. Compared to other HF bands, in the WARC bands, contests are not possible. But it is, anyway, an interesting frequency. The characteristics are quite like those of the 15 meters but with a less extreme dependence on the solar cycle, but it is an unpredictable frequency, and very often, conditions can be found equal to 20 meters. When the solar cycle is at its maximum, the openings are near that continuous and the band can be opened day and night every day, allowing connections in all directions including trans-polar paths. The progressive decrease of atmospheric noise, which is beginning to be felt significantly and the lower presence of active stations, helps to give the impression of a quiet and not noisy frequency.
When solar activity decreases, the band closes after sunset. During the day, propagation is open to medium and low latitudes (equatorial zone), allowing connections in the north-south direction, especially around the central part of the day.

Propagation with USA

A separate speech deserves about propagation with the United States.

QSO with the east coast are easy, thanks to the considerable number of active stations and a favorable skip. The strongest signals come from the Atlantic-facing states, while they decrease as we proceed towards the internal states. On the other hand, connections to the west coast (California, Oregon) or Alaska become quite rare and sporadic. I tried to explain this thing to myself, which could be due, on the one hand to the substantial difference of the signal path and on the other, to the skip, which is about 3000 km longer, so basically you need an extra "bounce" of the electromagnetic wave. Skip with east coast is around 6500 km, while skip with west coast is about 9500 km. However, the rarity of the openings with California is due to the diversity of the path, which passes over Greenland, at a latitude around 70° North. We know that propagation at high latitudes is not always favorable since it suffers even more from solar activity. So, conditions may not always be optimal to ensure good reflection of the electromagnetic wave and attenuation can be considerable. Conversely, the paths destined for the East Coast of America pass further south, above the Atlantic Ocean, indicatively around 47° North latitude, therefore with more favorable reflections. The same or perhaps even more pronounced discourse, can be applies to western Canada and Alaska, but it should be remembered that the observations become more difficult given the fewer stations operating from these countries.

The Ionosphere at high latitudes

The ionosphere at high latitudes **(1)** has different peculiar properties, since it is more exposed to the effect of perturbations whose origin is in interplanetary space and magnetosphere. Within the magnetosphere, the volume is shaped by the solar wind, the magnetic field's force lines pass horizontally above the magnetic equator, at a limited distance from the earth. The situation at high latitudes is different: the lines of force, at which vertical, move a lot away from the earth, towards the external

magnetosphere, while the charged particles of the "wind" are unable to penetrate this curtain transversely, glide smoothly along the lines of force stretched towards the tail. The outer magnetosphere subtracts energy from the solar wind from the place, at high latitudes, to weak daily secondary storms, which stir up the ionosphere of those areas. While the ionosphere at high latitudes is in a state of permanent agitation, with a dynamic and very variable F region, the ionosphere at low latitudes is protected from such events. However, we are in a close range to the area of this almost permanent agitation and are indirectly involved in it, whenever the solar wind increases as a result of a medium-intensity solar event.

Short skip

Propagation with Europe is commonly opened during daylight hours. The minimum skip is around 1200 km. and this, under normal conditions, excludes QSO with the nearest countries of Central Europe, but allows good connections with Spain, United Kingdom, Scandinavia, Greece and North Africa. I noticed a very favorable skip to the UK; The signals are strong, but this is also favored by the fact that there are many active and well-equipped stations operating from Great Britain. Also noteworthy is the phenomenon of back scatter that can be found quite easily even on this band, backscatter is a diffusion of signals that after an ionospheric path, are scattered after a contact with the ground. Very often the MUF are favorable in certain directions by propagating the signal in a well-defined area, so it happens that the one station is received beaming the antennas in that direction where the back scatter takes place, instead beaming directly. Another phenomenon similar as a back-scatter mechanism but different in the cause, is what I called reflected propagation. This is an anomaly in signal propagation introduced by signal diffusion due to very reflective ionospheric bubbles, as can happen for example along the terminator line. It is a mechanism found several times through field test experiments and applicable for

stations located close. For example, I have had the experience to connect a station from Czech Republic that radiated beaming his antenna in north-west direction and I beaming my antenna in that same direction and where at that moment there was the terminator and where the MUF was favorable. The signal is recognizable because it is subject to a strong echo effect, like that for back scatter.

Tropospheric propagation

Thanks to my field experiments in this band, we have confirmation of the possibility of connections supported by the troposphere, like what happens for the highest HF bands, 10 meters or even for the VHF band of 2 meters. The quality of the signals, however, depends very much by the antenna system and TX power. In fact, the experiments confirm that the tropospheric DX is possible only with efficient antenna systems, dedicated to this frequency. For example, I would like to report a QSO, made in May 14, 2005, at 07.00 UTC, on the frequency of 18,144 MHz with the station IK4UPI from Parma (skip of about 150 kilometers). A peculiar feature of this signal is that it was better received through reflection on the Venetian Prealps, as happens for those tropospheric signals I receive on the 2 meter band. My city is found a few kilometers from the first slopes of the Alps. The signal was stable but with sporadic and rapid strength increases (positive peaks).

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12 meter propagation

General features

It is a less frequented band and therefore the characteristics of propagation are little known. It is like 10 meters; however, it has the advantage of longer openings. Like the 10 meters, it is very affected by solar activity and the level of ionization, therefore, it is a daytime frequency. At our latitudes, in the low periods of the cycle, the propagation closes near the sunset, in the

highest phase of the cycle, the propagation lasts even after sunset with the possibility of good but unpredictable night openings (especially in the early hours). In the years straddling with the highest phase of the cycle, the band allows DX connections even several hours after sunset, with low TX power or inefficient antennas. Possibility of connections via sporadic E short skip, like the band of 10 meters. The absent atmospheric noise and extremely low attenuation allow to make excellent connections even with very low power and allows to listen signals that on other bands would be covered by noise. The advantage of the 12 meters is that it combines the best of 15 and 10 meters.

Space weather and solar cycle

In the following table you can find a prediction model that considers the intensity of the solar flux combined with the level of geomagnetic activity. The propagation is influenced by the magnetic field although in a less way than the lower bands of the spectrum, so the best conditions especially for those more exposed paths, such as those that cross the polar areas, you always need low K and A indices.

- Index K <3 (Index A<16) – Solar flux SFI 150 to 200: Propagation from good to excellent
- Index K 3 to 4 (Index A 16 to 27) – Solar flux SFI 120 to 150: Propagation from sufficient to good
- With the K index from 5 to 6 (index A from 48 to 80) the propagation begins to deteriorate even with high flux values
- Index K 7 to 9 (Index A 140 to 400) propagation is poor or even closed

- Maximum phase of the cycle: Two years before and two years after the solar max, communications to all directions with frequent openings are possible even several hours after sunset.
- Intermediate phase of the cycle: The band is open to medium and low latitudes, but only during daylight hours, with rare openings after the sunset.
- Minimum phase of the cycle: In years of declining activity the opening hours via F2 gradually decrease and the propagation is therefore often closed even during the hours of the day, the openings after sunset are exceptional and in correspondence with best conditions.

All observations refer to an average latitude such as that of Northern Italy and Central Europe, as latitude changes progressively the conditions that improve going south and worsen heading to north.
(The MUF gradually rise towards to the equator.) I have had the opportunity to discuss propagation on several occasions with OM located at the high latitudes, Scandinavia and even Alaska, and they confirm to me that the bands always close much earlier , the propagating windows are always quite small and very strong signals are quite rare. At these latitudes, the propagation is more exposed to changing space weather conditions.

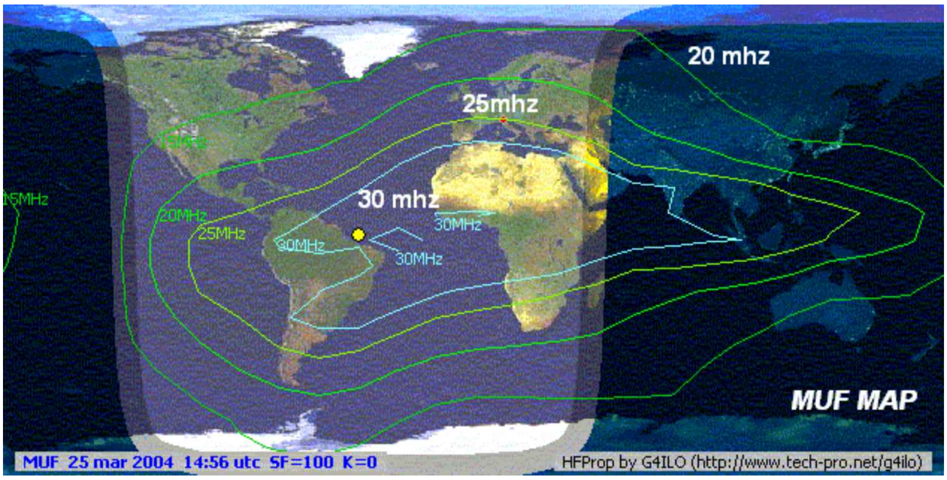


Fig. Thanks to G4ILO's HFPROP program, I have created this illustrative map using a solar flux value of 100 and a quiet geomagnetic field. These parameters were chosen during one of the seasonally optimal times for DX communication—straddling the equinoxes. During summer, for instance, the higher position of the sun for several hours each day leads to increased attenuation. This results in greater density in the D and E regions of the ionosphere. Consequently, the 15-meter band (similar principles can also apply to the 10-meter band) performs better than the 17 and 20-meter bands during summer afternoons. This map partially encapsulates the earlier discussion, specifically the concept of the Maximum Usable Frequency (MUF) gradually decreasing from the poles towards the equator. In Italy, the MUF typically

hovers around 25 MHz, theoretically enabling the use of the 12-meter band.

Shadow zone

I would like to better understand the concept of shadow zone. The shadow zone is an area delimited by a limit radius, within which it is not possible to receive a station, a distance that depends not only from the frequency, but also from the intensity of the solar flux and the value of the geomagnetic field. The 12 meters shadow zone is quite wide and, in any case, commonly over 1000 km of radius. The skip increases for northbound propagation and tends to decrease to the south.

Grey Line

In the same way as for the lower bands, it is possible to take advantage from the positive effect of the grey line, however, contrary to what happens in the lower part of the HF spectrum, where the best conditions for working along the terminator are usually passed from night to day and therefore in the early morning, on the highest bands such as 12 meters, the favorable conditions are on the illuminated side of the world that is darkening with the evening. The "useful time" is related to the time of the solar cycle.

Geographical position

In the highest frequencies and for the DX, geographical location has a significant importance. With a covered horizon even of few degrees, the connections via F2 in 12 and 10 meters over the long distance, become difficult, (for short skip connections the problems decrease, as well as decrease for the DX in the lower bands of HF, the low bands in fact, are less penalizing in terms of geographical position). I was impressed and share an article published on “Radio Rivista” many years ago, written by Edo Bini, I2BAT,

which thanks to intelligent considerations and trigonometric calculations, reported how the DX becomes prohibitive for those stations that have the horizon covered and he also provided some critical limits that should be the following:

- 6 degrees for 10 meters
- 7 degrees for 12 meters
- 8 degrees for 15 meters
- 15 degrees for the 20meters

30 meter propagation

General characteristics

The propagation characteristics of this band present some intriguing aspects, particularly because they are less influenced by the solar cycle and blend the attributes of both daytime and nighttime conditions. The usual seasonal and daily fluctuations are less pronounced, facilitating excellent DX connections throughout most timeframes. Despite its potential, this band remains obscure and underexplored. Exclusively allocated for telegraphy and digital modes, this band does not permit voice transmissions. Its behavior is reminiscent of the 40-meter band, with added characteristics akin to the 20-meter band, particularly noticeable during the summer months. In the daytime, skip distances range between 600 and 2000 kilometers, extending progressively as night falls, thus allowing for DX opportunities into the darker hemisphere. This band remains open around the clock due to these conditions. However, the band's availability is contingent upon the ionization levels in the E and F regions. During nighttime and in years of minimum solar cycle activity, the band often exceeds the Maximum Usable Frequency (MUF) for numerous DX paths. Conversely, during the daytime, especially in the troughs of the solar cycle, it often becomes the highest usable frequency.

Absorption

As always, absorption plays a significant role. Right-hand connections should always be looked for on twilight paths. Compared to 40 meters, however, the openings can be longer, and the low level of noise (atmospheric and local), the band is excellent for QRP operations. Directions are favored with the path in the dark. In local evening, the best directions are to east, while early morning the best conditions are in the opposite directions.

Space weather and Propagation

The band is not overly sensitive to solar flux, but it needs low geomagnetic indices. Propagation here also requires low values of the geomagnetic indicators K and A, especially for connections over longer distances and between the two hemispheres, when the signal needs to pass over the equator. High values of the geomagnetic field deteriorate propagation especially on polar paths and partially or totally inhibit the positive effect of twilight propagation (also important for the 30 meter band). We know that when the indices are very high, there is a progressive deterioration of D region, with a consequent increase in absorption, the band is still significantly affected by D layer attenuation. The general rule is always the same: The conditions are better when geomagnetic activity is low, even in the previous 24/36 hours and the value of the SFI (solar flux) is kept, this is, due to the time constant, the effects of a rise in activity are felt after a few days, therefore for a more reliable forecast, medium-long-term monitoring is recommended.

Below are some indicative data on the condition of the indices for the 30 meter band:

- Index K <1 (Index A<4) – Solar flux SFI 120 to 150: Excellent propagation
- Index K 2 to 3 (Index A 7 to 16) – Solar flux SFI 90 to 120: Good propagation
- Index K >3 (Index A > 27) – Solar flux SFI 70 to 90: Normal propagation
- With K>4 and A >48 indices and solar flux SFI values < 70: Poor propagation

Until now, we have talked about the high and low phase of the cycle, since however this is not a quantifiable numerical value. Just below, I report an objective and numerically quantified situation of how the situation of the solar cycle is considered based on the values of the number of spots and the Solar Flux:

- Number of SSN spots < 50 – Solar flux SFI < 100: Low phase of cycle
- Number of SSN spots from 50 to 90 – SFI solar flux from 100 to 140: Average phase of the cycle
- Number of SSN spots from 90 to 120 – SFI solar flux from 140 to 170: Medium high phase of the cycle
- Number of SSN spots >120 – SFI solar flux >180: High phase of the cycle

I would remind, that the relationship between the number of spots and the solar flux, although proportional, does not follow a linear law. The flux indices start from a minimum value of 67, while the maximum value has been set at 300, because it is the highest recorded and so far, exceeded value.

Propagation via E layer

E Region is between 90 and 130 km above sea level and tends to disappear at night. The most intense ionization, in fact, is found a few hours after the sunrise and gradually decreases after sunset, but it remains a dense level of residual ionization that sometimes also affects the night propagation. In principle, this layer supports daytime propagation in 30 meter band, while the night residue can contribute to long-distance propagation in the same way as in the lower bands for the formation of ionospheric wave guides.

Conclusion

Here at the end, the series of pages dedicated to the study of propagation on all HF amateur bands that has been realized by combining the theoretical part with the field experience of the author and other radio amateurs. The extensive literature dedicated to Ionospheric and HF propagation, is limited to making brief notes on the characteristics of propagation on each individual band,

the aim of this research is to further deepen the subject and stimulate interest in research and studies about HF propagation.

Notes:

1) Below there is a table which summarizes, according to degrees of latitude, the three-latitude zone which are conventionally distinguished by the propagation.

Geomagnetic latitude scale:

- High latitudes: 0-20 degrees
- Mid latitudes:20-60 degrees
- Low latitudes:60-90 degrees

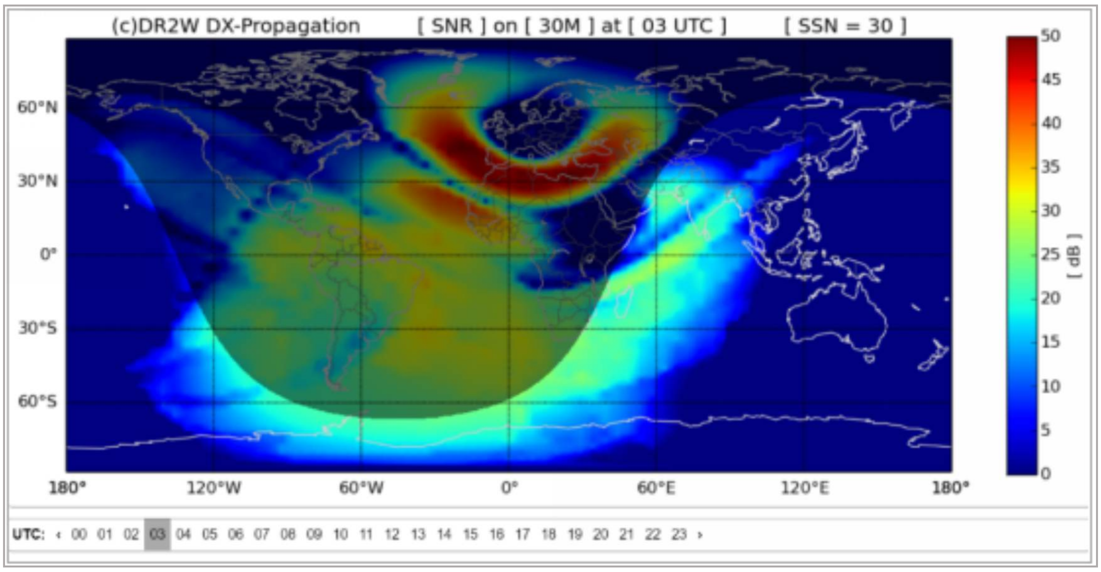


Fig. Simulation with Voacap of propagation at 30 meters at night (03.00 UTC) with low number of solar spots (SSN=30). Centered on Europe.

Image credits: DR2W DX Propagation v.0.9.4, calculated with: VOACAPL by HZ1JW

60 meter propagation

This band was recently allocated to radio amateurs in 2018, with a frequency range of 5351.5-5366.5 kHz, and it holds a secondary service status. In Italy, the power limit is a maximum irradiated equivalent isotropic power of 15 Watts. The band supports SSB, CW, and digital modes. In the SSB mode, conventionally, frequencies are channeled around 5360 and 5363 kHz. Situated between the 80 and 40 meters bands, this band serves as a bridge. Radio operators turn to the 60-meter band when propagation conditions are unfavorable for operating on 80 or 40 meters, especially for short-distance communication. Although I have not yet had the opportunity to experiment and fully understand the propagation on this new band, I would like to share some initial impressions. Compared to the 80 meters band, this band is less affected by D-layer absorption, leading to improved daytime conditions. The propagation characteristics resemble those of the 40 meters band, albeit with more instability.

Summary of some key aspects of propagation on the 60-meter band:

Average Distances: The 60-meter band is commonly used for medium-range communications. Due to its more limited coverage area compared to other HF bands, it is particularly suitable for communications within a specific geographical area, such as a country or a region.

D-Layer Absorption: Compared to some higher HF bands, the 60-meter band is less affected by D-Layer absorption, which is a part of the ionosphere that can absorb radio waves during the day. This makes the band more reliable during daylight hours.

Nighttime Propagation: Although primarily a daytime band, nighttime propagation on the 60-meter band can be influenced by ionospheric and atmospheric conditions. On some occasions, conditions may enable slightly greater-than-normal distance communications.

Seasonal Conditions: As with many HF bands, propagation conditions on the 60-meter band can vary with seasons and solar activity. During periods of high solar activity, propagation might be better, and the covered distances could increase slightly.

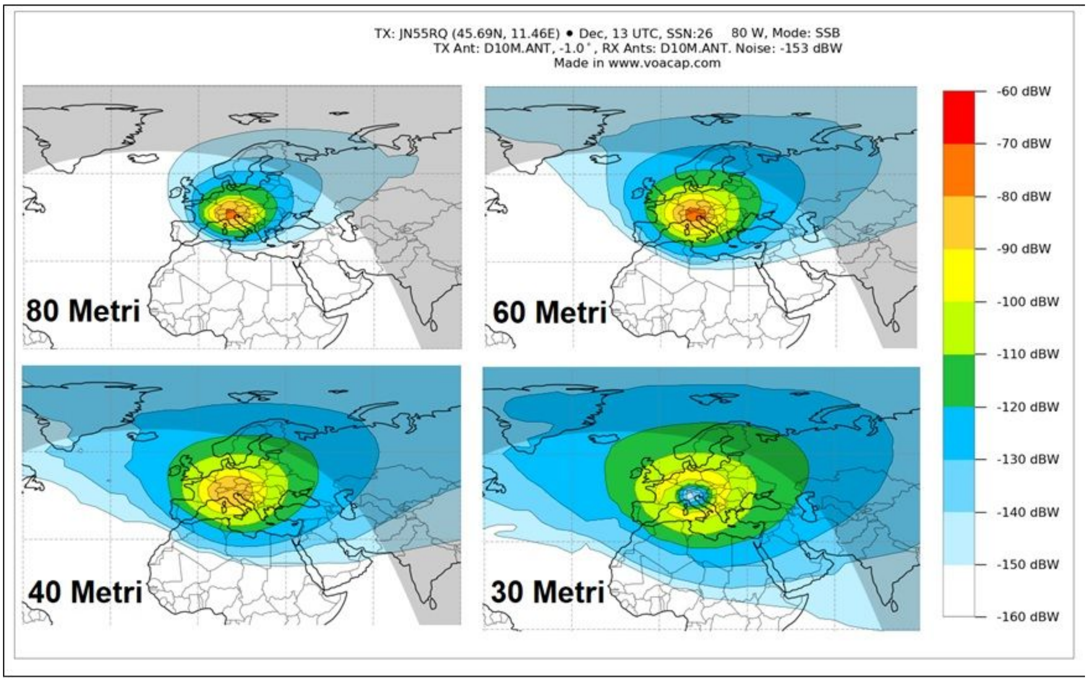


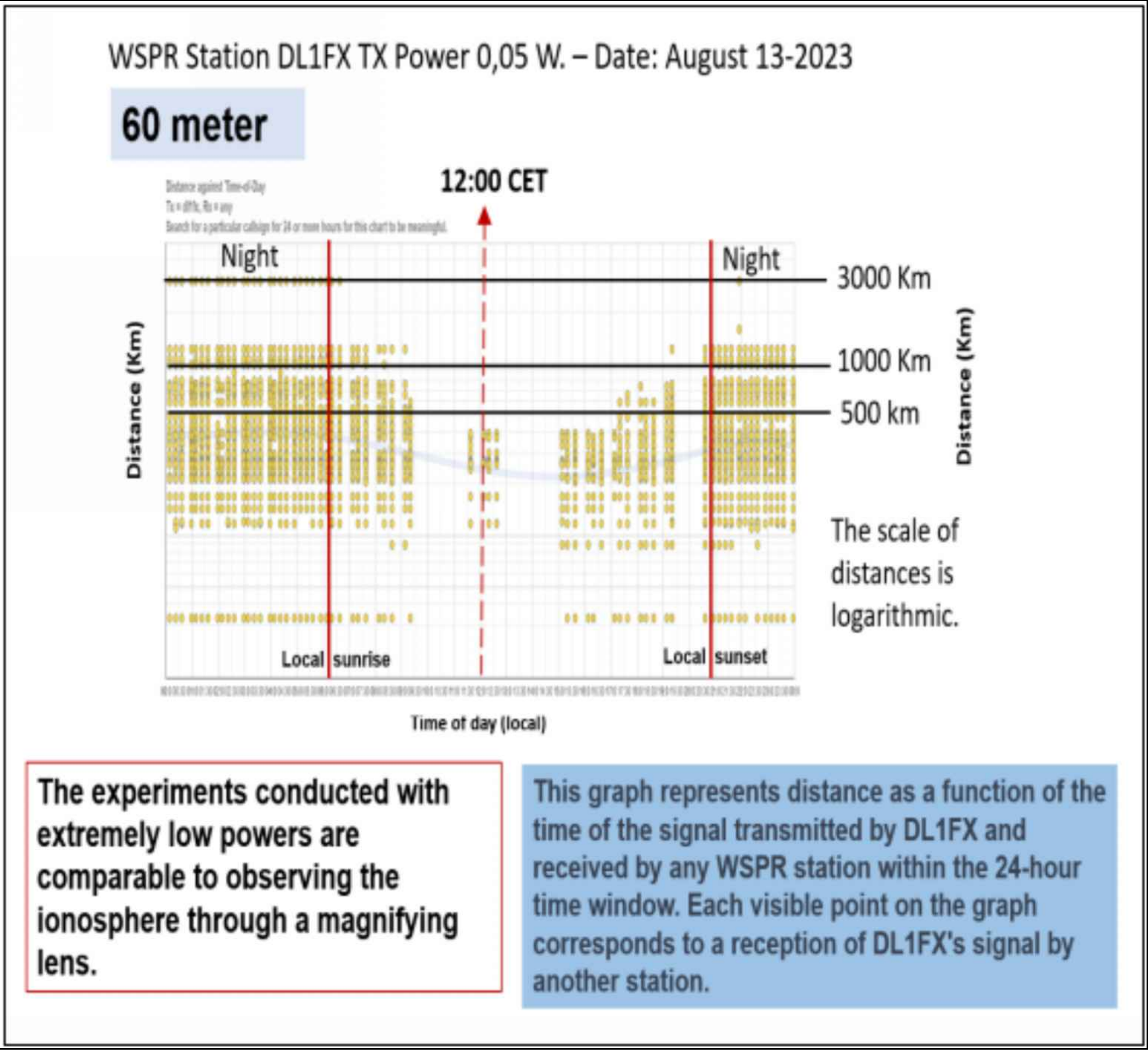
Fig. For illustration and comparison, these maps are centered on northern Italy, depicting potential coverage at 30, 40, 60, and 80 meters during 13 UTC in December. The same operating conditions apply to all frequencies: a half-wave dipole antenna and 26 sunspots. When comparing the 60-meter range to the 40-meter range, it becomes evident that the former provides stronger signals for short skips on a local level, within the national scale. However, apart from this distinction, the 60-meter range appears quite like the 40-meter band.

Image credits: Maps were generated using the VOACAP online program by Ari Perkiömäki (OH6BG), James Watson (HZ1JW), and Juho Juopperi (OH8GLV). Creative Commons Attribution-ShareAlike 2.0 (CC BY-SA 2.0).

WSPR-ROCKS graph

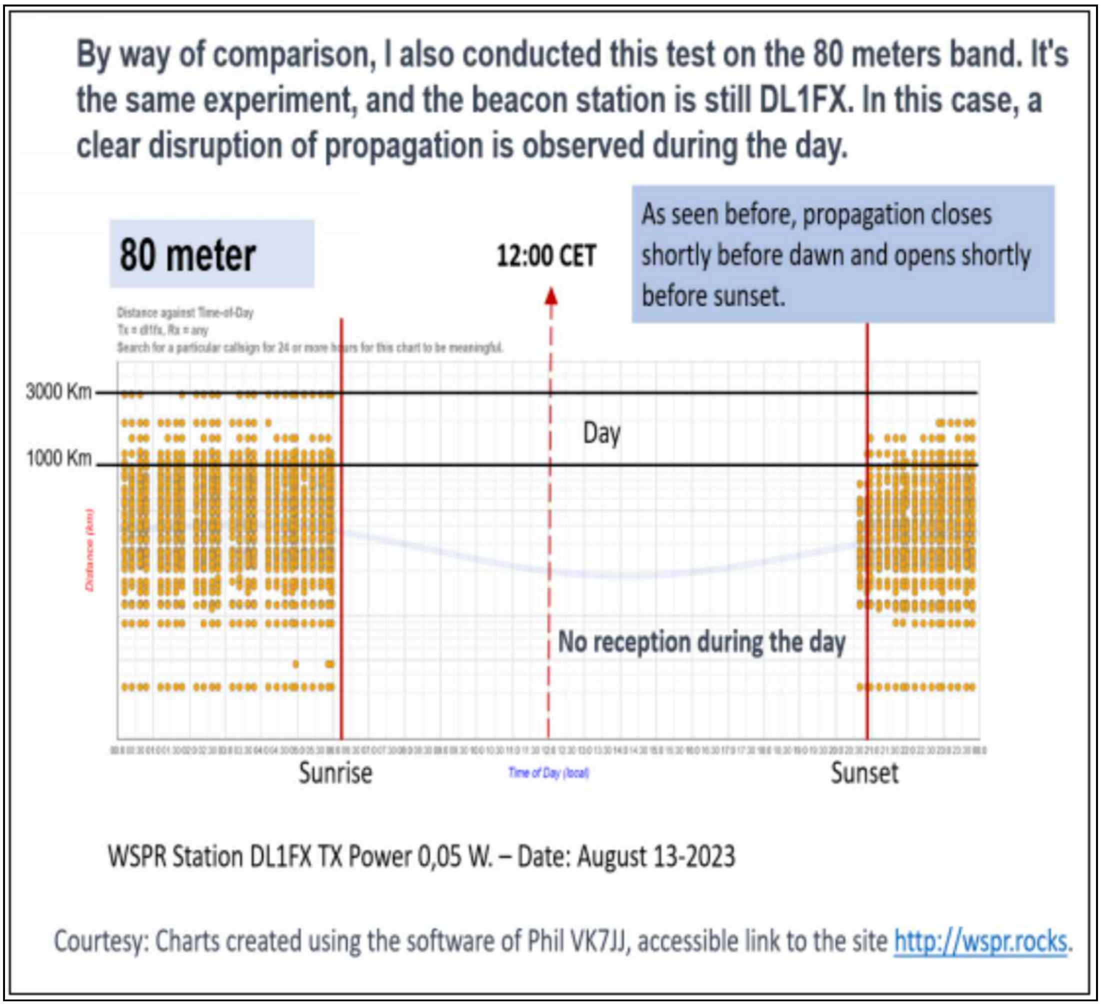
I used the WSPR ROCKS software, developed by Phil VK7JJ, accessible at the following address: http://wspr.rocks. The aim was to provide an example of the evolution of propagation on the 60-meter band over the course of a full day. Analyzing the generated graph, a stable behavior during the nighttime hours becomes evident, while signs of instability are

observed during the daytime hours. Specifically, a shortening of distances compared to what occurs during the nighttime hours can be observed. It is interesting to note how the behavior changes around sunrise and sunset. (On the vertical axis, the distance in kilometers from DLIFX is shown, and on the horizontal axis, the time is indicated).



WSPR ROCKS is a search and spot analysis software based on the WSPR system: it is fast, user-friendly, and thorough. It offers spot maps, charts, tables, and advanced search capabilities for statistics.

Courtesy: Charts created using the software of Phil VK7JJ, accessible link to the site http://wspr.rocks.



WSPR test: Band comparison 40-60-80 meters over distance of 761 kilometers To verify the behavior of the three different bands (80-60-40 meters). I have chosen a day in December as an example: December 15, 2020, starting from 00:00 UTC until December 17 at 08:00 UTC and recorded the reception data of two WSPR beacons. DL1FX as TX station and

IW2NKE as RX station. The distance between the German Land of Hesse and the WSPR beacon of IW2NKE is 761Km. IW2NKE's WSPR receiver is in Marche region, near Ancona. I reported all the data, band by band and made a graph. The graph is “talking” and give us an idea of the trend. It is immediately noticeable that the 60 meters have a behavior like 40 meters. With long night closures. The 60 meters have an early opening compared to 40 meters, they tend to open first before dawn, while the 40 meters open later. It can also be seen that the 60 meters are most affected by the absorption of D layer. In fact, the signal, gradually tends to decrease during the day. The best time is on the grey line. The 40 meters show a peak in the early morning. The band of 80 meters, has the behavior that we can expect, with long and regular night openings even with the usual ionospheric variability, and propagation closure immediately after dawn. The graph always shows the usual hysteresis of the ionospheric layers. In addition, given the great variability of the ionosphere, tests done on different days, can give different results.

IMPORTANT NOTE: On the graph, the signal strength in 40 meters seems much higher than that of the 60 meters. The average of the signals is similar. This difference is due only to a problem of scales in the realization of the graph.

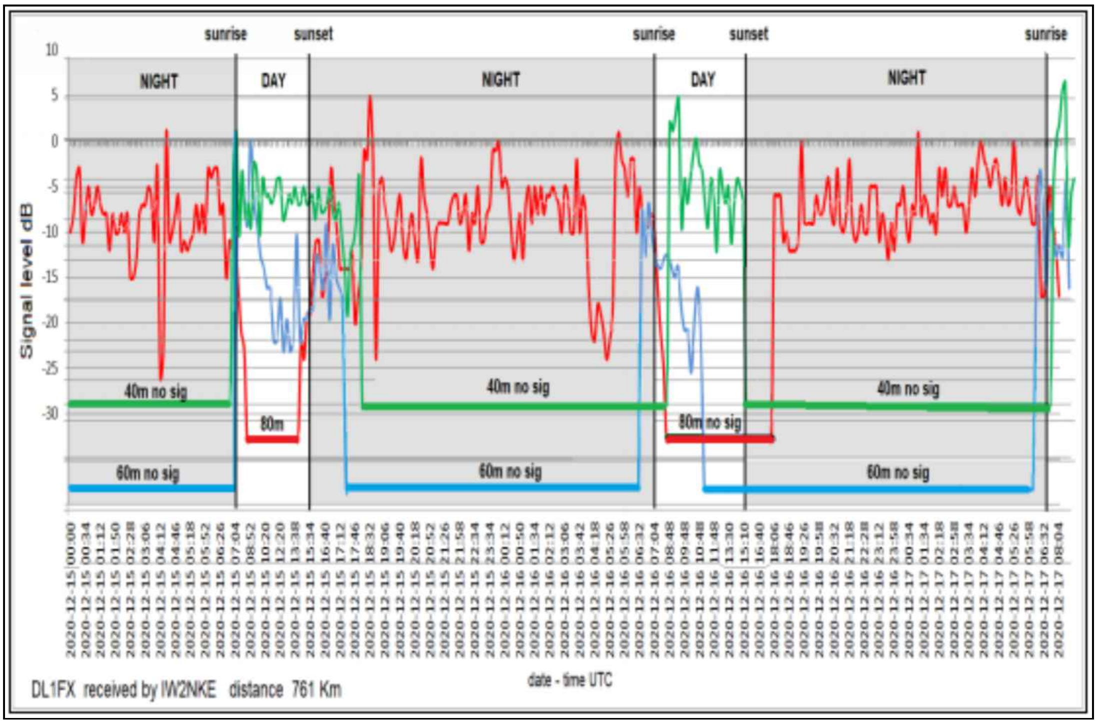

sunrise
sunset
sunrise
sunset
sunrise
NIGHT
DAY
NIGHT
DAY
NIGHT
Signal level dB
40m no sig
80m
40m no sig
80m no sig
40m no sig
60m no sig
60m no sig
60m no sig
date - time UTC
DL1FX received by IW2NKE distance 761 Km

Fig. Simultaneous reception comparison graph on three bands 40-60-80 meters. Of the German WSPR TX station DL1FX heard by IW2NKE (WSPR mode – beacon mode). Data December 2020.
Legend: Red line=80 m. Blue line=60 m. Green Line=40

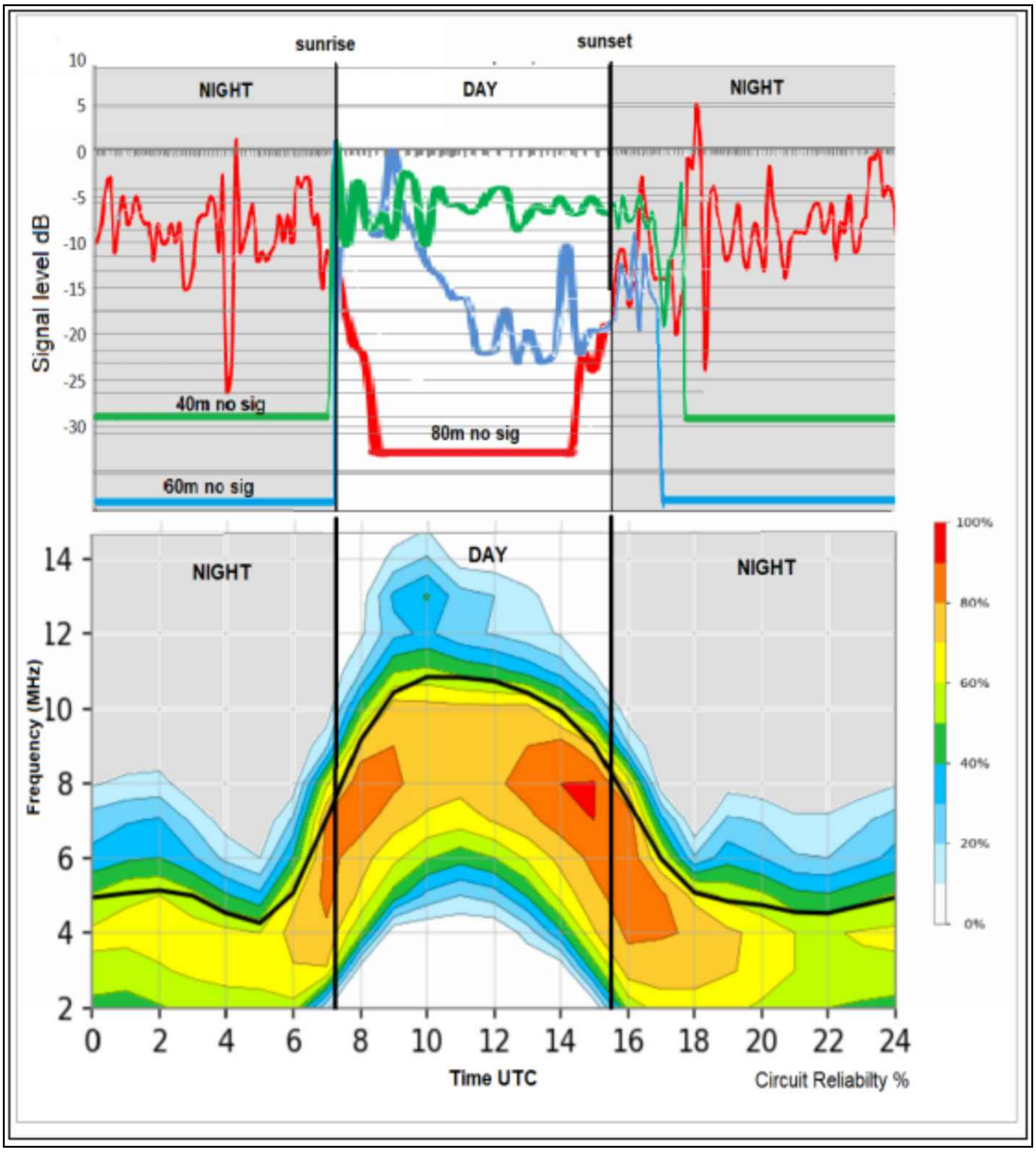


Fig. Comparison between the simulation made with VOACAP, (lower part *of the graph) showing the "Circuit Reliability" in % that is,* the most reliable frequencies that guarantee the connection of this path *and the real experiment done with WSPR, between DL1FX and I2NKE. The forecast fits well with the specific experiment, especially for the 80 meters. But I must specify that the model is based on a transmission power of 0.5W while DL1FX transmits with only 0.2 W.*

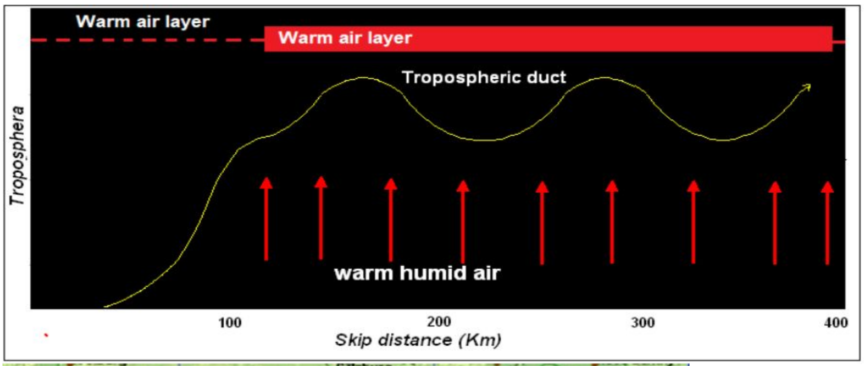
6 meter propagation

General features

The six-meter band combines the characteristics of both HF and VHF, enabling a wide range of experiments with various propagation modes. Connections become possible through the utilization of tropospheric propagation, ionoscatter, or F-layer propagation. You can experience sporadic E, meteor scatter, reflection via Aurora, and, for the best-equipped stations, even Earth-moon-Earth (EME) communication. The propagation characteristics can change within a matter of minutes, transitioning from a closed band to long-distance openings, and vice versa. Like the 10-meter band, DX propagation via the F layer is influenced by solar activity. However, during favorable moments, thanks to lower absorption and the option to employ efficient directional antennas, this band allows remarkable connections with all continents, even for QRP stations. My intention is to delve deeper into the various phenomena that contribute to propagation on 50 MHz. I will draw upon my personal practical experience, insights from other amateur operators, and comparisons with current theories in propagation studies, as always.

Tropospheric propagation (tropo-scatter)

The troposphere can be used to support signals in the same way as 2 meters. The distance of the connections is lower than the 2 meter band, but not so much. The general impression among ham radio community is that tropospheric propagation is not qualitatively comparable to the 144 MHz My experience, however, is that if the station is well equipped, connections over the 700 kilometers are possible with some regularity. Interesting is the possibility of exploiting the tropospheric ducts that can be formed in the presence of favorable conditions especially above the sea.


Warm air layer
Warm air layer
Tropospheric duct
Troposphera
warm humid air
100
200
300
400
Skip distance (Km)


I3
Tropospheric duct above the Adriatic Sea (Skip 560 Km.)
I7
Salzburg
Innsbruck
Trento
Verona
Venezia
Milano
Brescia
Torino
Parma
Bologna
Genova
Firenze
Livorno
Perugia
Terni
L'Aquila
Rome
Latina
Napoli
Foggia
Bari
Potenza
Taranto
Catanzaro
Messina
Palermo
Catania
Siracusa
Bastia
Ajaccio
Sassari
Cagliari
Zadar
Split
Mostar
Sarajevo
Zenica
Tunis
Nabul
Birkirkara

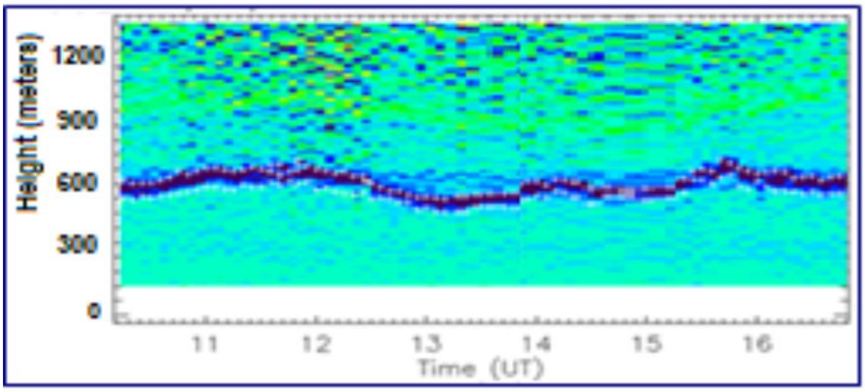

Height (meters)
1200
900
600
300
0
11
12
13
14
15
16
Time (UT)

Fig. As an example, the map shows the geography of a tropospheric duct that is often formed over the Adriatic Sea and that allows excellent communications with exceptional signals between Veneto and Puglia, from Gargano to Salento. Sometimes the duct extends to the Ionian Sea (Skip of about 1000 km.), allowing you to connect the Island of Corfu and the coasts of Greece. I have practical confirmation that this tropospheric duct is accessible for both 144 MHz and 50 MHz frequencies, as I was able to personally experience during summer 2003 by simultaneously QSO with Puglia region in 2 and 6 meters. A question is still open: could the duct also be usable for the 10-meter HF band?

Sporadic E

Sporadic E is one of the most common modes of propagation on 6 meters. We have previously discussed this phenomenon broadly and in detail in the preceding pages. In the subsequent pages dedicated to the study of Es, I will delve into the topic extensively, examining training mechanisms and discussing various scientific hypotheses. My intention is to explore additional facets in greater depth and, if possible, offer further avenues for thought and research inspiration. There appears to be a correlation between the formation of Es and thunderstorms. Recent studies conducted by Dr. Volker Grassmann - DF5AI - support this hypothesis, demonstrating a relationship between lightning activity and Es propagation openings in Europe. While we cannot assert this with absolute scientific certainty, a connection with Es formation is suggested. The hypothesis revolves around convective effects generated by thunderstorms, which give rise to gravitational waves (1) (See notes). These waves propagate from the lower atmosphere to the upper atmosphere, potentially triggering the

phenomenon. This introduces the possibility of a dynamic process occurring at mid-latitudes, akin to phenomena observed in the tropical atmosphere, such as TID (mobile ionospheric disturbance) and equatorial F spread, both of which are attributed to the convective motions of thunderstorms. This is a hypothesis I am eager to explore further. As widely recognized, sporadic E in mid-latitudes can occur at any time. However, in our hemisphere, within the 6-meter range, its prevalence is greater during May, June, and July. The optimal times for observations are from 9 am to 12 pm and, notably, from 5 pm to 8 pm. These propagation openings can endure for mere minutes or extend over several hours. Notably, openings in VHF on 2 meters, and consequently 6 meters, tend to exhibit distinct geographical selectivity. Even distances of 20 to 30 km can significantly affect station reception, ranging from excellent clarity to complete inaudibility. Several indicators provide insights into these openings: the phenomenon can manifest on the higher bands of HF (21/28 MHz) and swiftly extend to even higher frequencies. A sudden reduction in skip distance at 28 MHz (400-500 km) can serve as a promising indicator that the Es MUF (Maximum Usable Frequency) has reached 50 MHz. Similarly, an abrupt reduction in skip at 50 MHz (500-700 km) may signify that the MUF supports propagation on 144 MHz. After years of research, I have developed the belief that ES is intricately linked with meteorology (2) and that solar radiation plays no role in sporadic E propagation.

Distanze di Propagazione via Es sui 50 mhz
Riporto di seguito una guida generale delle distanze possibili con Es, 2 Es a propagazione Es multisalto

Es singolo salto
distanza minima 500 – 650 chilometri
distanza ottimale 1500 – 2000 chilometri
distanza massima 2200 – 2400 chilometri

Es doppio salto
distanza minima 2800 – 3000 chilometri
distanza ottimale 3200 – 4000 chilometri
distanza massima 4400 – 5000 chilometri

Es triplo salto
distanza ottimale 4800 – 6400 chilometri
distanza massima 6900 chilometri

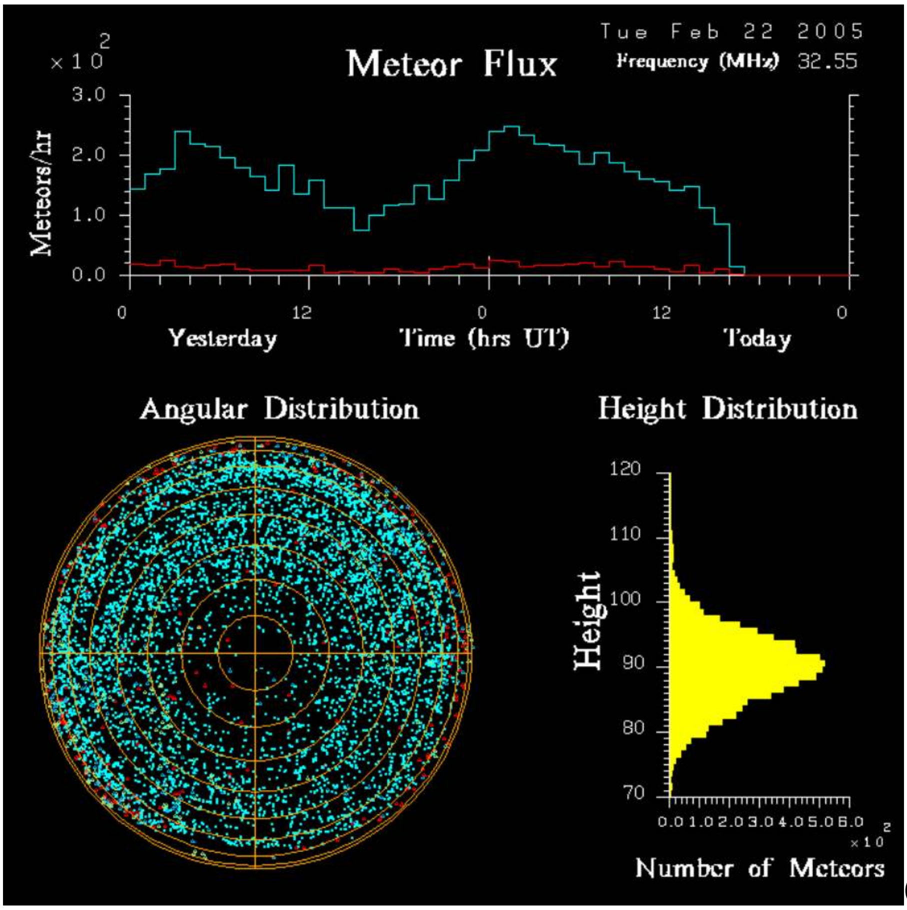
Es multi salto
Massima distanza record: ~ 12,500 km - 48.2597 chE2 Iran ricevuto via multi-salto sporadic E, da N5HV New Mexico - USA

Propagation via Aurora
Auroral zones have a considerable influence on radio propagation in VHF because when auroral activity is high, the auroral curtain can be used as a signal reflector. The best times range from 4 pm to 8 pm local time and can be expected by checking the indices of geomagnetic activity: A sudden increase in the K index can be an important signal of possible auroral activity, even if there are specific portals dedicated to aurora observation on the web network that allow perfect aurora monitoring in real time. The active aurora tends to degrade signals in the HF but can support exciting connections for VHF operators with QSO up to 2000 km. In 6 meters exceptional events have led to connections over 2200 km. The use of beam antenna is essential because there is a need to radiate towards auroral activity, despite this, the quality of the auroral signal is degraded because of the scintillation caused by the unstable and disturbed nature of auroral particles. The signals are therefore distorted and wider than normal. Communications are easier when auroral activity is low and visible on the radio horizon, however

connections are possible even when the auroral activity is also 1000 km away and therefore well below the visible horizon. This means that from northern Italy the opportunities are greater than you think, even if it requires exceptional circumstances. The best times are towards the end of the afternoon and in the early hours of the evening. The best bargains are around midnight local time during major geomagnetic storms.

Meteor Scatter

Meteor scatter connections take advantage of the ionized trail formed by the ablation of meteorites entering the Earth's atmosphere at a speed of 100,000 km/h. This phenomenon occurs in E region, where the chances of collision with gas molecules are greater. This ionized trace even if the body that generated is small, at the time of formation it is a cylinder with a diameter of 20 cm. And inside this cylinder, the density of free electrons is much higher than in the surrounding atmosphere. In the subsequent dispersion the value of free electrons decreases but for longer or shorter times a VHF wave train directed towards the meteor trail has a non-specular reflection (scatter) able to support connections well beyond the optical horizon. The widespread nature of the reflection causes the signal to be significantly distorted.



On the web you can consult a whole series of monthly updates that report the meteor activity and that therefore provide a useful indication on how to plan the activity for this fascinating way of propagation.

Image: Colm meteor radar – Germany

Features of METEOR SCATTER / METEOR SKIP

- Best time: August and October, through early January
- Daily peak: 0500 to 1200 local time (for night swarms)
- Receiving distance: from 1000 to 2000 km.
- Antenna pointing: E/NE (although any direction is possible)
- Signal duration: micro-scatter, 1 sec., General, 2-3 sec, Elapsed scatter, 10-20 sec, major scatter, 30 sec to 1 min.

EME

Earth-moon-earth (EME) communications use the surface of our satellite for signal reflection. The earth-moon-earth path allows flow rates comparable to the connections via the Ionospheric region, but it can only be achieved by stations of remarkably high efficiency and with considerable power. The signal path is over 700,000 km and absorbs a lot of energy. The lunar scatter then introduces another source of further dispersion, although the visible lunar disk has different scattering properties.

In the 1950s, radio waves, as well as visible light and infrared radiation, were found to be reflected to earth, from small regions located in the center of the visible disk. The moon in fact seems to have a different behavior for radio waves than visible light.

Propagation and solar activity

Conventional openings via F region are concentrated in the period of high solar activity. In the lower phase of the cycle the propagation conditions are poor. However, major solar events, usually linked to geomagnetic disturbances, cause a sudden increase in the critical frequency Fc, although the chances of the band opening are low. We have seen how, at least in the first phase of major solar events, they can occur circumstances for a sudden propagation improvement on all bands and this is also valid for 6 meters. While the lower bands are then penalized by increased absorption, the 50 MHz are almost immune from the phenomena of ionospheric absorption, even when the upper part of the ionosphere is strong ionized. Magnetic field plays an important role especially when operating with weak power, as in case of amateur stations.

The ionosphere is a magneto plasm, that is, a plasma immersed in the geomagnetic field, so the fate of a signal that penetrates a layer depends and not a little, on geomagnetic activity.

Antenna irradiation angles

Another fundamental aspect of the possibility of making the connection, concerns the irradiation angle of the antenna. Especially in a band such as 6 meters, when the conditions of the ionospheric medium are often at the limit and a low vertical angle of irradiation becomes important to exploit the openings via F2.

Noise

The level of atmospheric noise is much higher in 50 MHz than 144 MHz. In 50 MHz, a quiet station has a noise temperature of 4,000 K = 12 dB compared to 1,000 K = 6 dB on the band of 144 MHz. In urban area, artificial noise is higher at 50 MHz However, the situation is always better than the HF bands since the dominant noise in 50 MHz is the galactic noise.

F2 layer propagation

In the high phase of the solar cycle, ionospheric MUF can rise above 50 MHz making long-distance propagation available even for 6 meter band. Fantastic intercontinental QSO, characterized by excellent signals, are therefore possible, as is the case for the HF band of 10 meters. The possibility of worldwide propagation via F region is particularly fascinating to study. Even for those people, who approach the 6 meters for the first time. They will soon find out that the openings are unpredictable although a more in-depth observation then leads to hypothesize several prevailing models. However, it is very difficult to predict when the band will open, especially for short-term forecasting (daily forecast). Unfortunately, there are no simple answers to this dilemma, there are some parts of F2 propagation that are known and understood, and some phenomena remain mysterious. To understand when the band will open, it is essential to understand why propagation opens via F2. A discussion of why signals propagate, must begin with some basic considerations on how radio waves behave in the ionosphere.

There are three basic elements:

1. The amount of ionization present in the ionosphere
2. The irradiation angle of the signal
3. The presence of large or small irregularities in ionization

These are key parameters in the F layer propagation process and although there are many external things that affect the condition of these three terms, in the end, propagation is a combination of these three factors. From a statistical point of view, F2 openings are very unlikely and while this may seem obvious, it has a particularly important consequence. Unlikely events in complex physical systems are often the result of a combination of factors, some of which can also be unlikely. This is certainly the case with F2 openings on the 6 meters, where propagation is always very close to the minimum limit to be able to receive a signal. In summary, we can say that we do not yet know well all the factors and we know even less, how they interact. Although F2 layer keeps a weak night ionization, F2 propagation over 6 meters is limited to daylight hours. There is a good correlation between the long-term average of the solar flux (10 cm radio-flux) and F2 propagation (due to the number of spots, flare count and many other measurements of solar activity). If the solar flux remains as a high average month after month, the propagation will be good. However, vertical incidence ionograms do not show a day-to-day correlation between flux fluctuations and the measured critical frequency (fc) that fixes the corresponding MUF. This is not intended to resize the role of solar flux; it is an important indicator of solar activity. It is certainly true that long periods with high solar flux values, imply good propagation, but it is difficult to establish the openings of a given day when the flux is at 300 or one day when the flux is at 150. Single days with a high solar flux value, they are less important than many days with high values circumscribed in the last 30, 40 days.

Winter anomaly

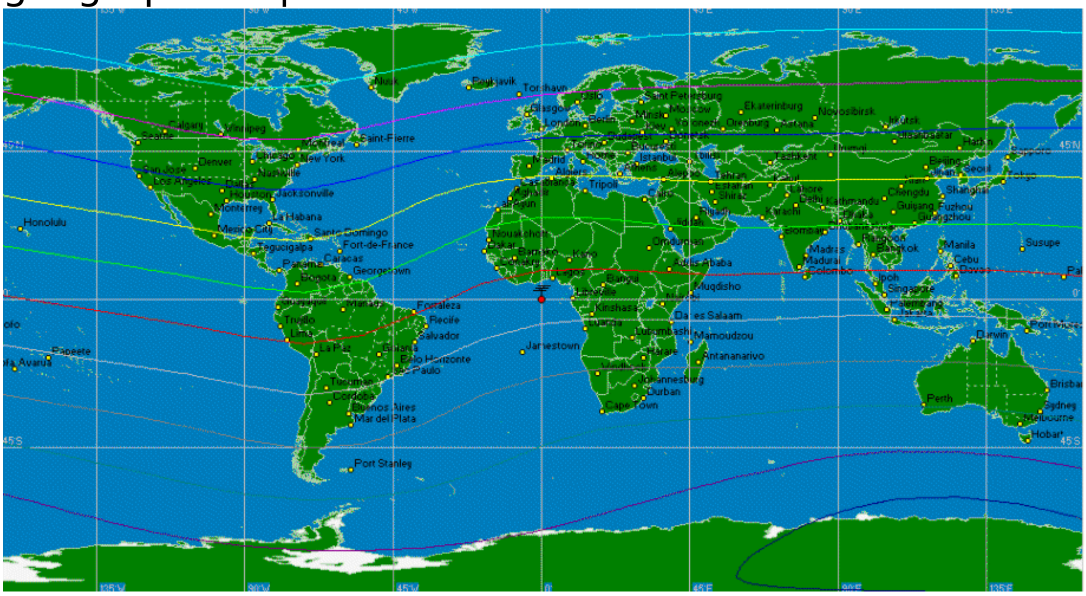
The winter anomaly introduces the greatest seasonal fluctuations near the solar maximum, where we can detect daily winter MUF even twice as large as the

respective daily summer MUF. This means that F2 propagation between two stations in the same hemisphere is better in Winter and during solar maximum. In the case of multi-skip connections in the north-south direction, the winter anomaly plays a different role. In one hemisphere it is summer while it is winter in the other. This penalizes the connections so much that, the best period for this direction is Spring and Autumn when the effects of the winter anomaly are homogeneously distributed in the two hemispheres (equinoctial improvement of propagation). Winter anomaly is not the only seasonal effect.

Trans Equatorial Propagation (TEP)

In areas between 20 and 30 degrees, both north and south of the equator, the influence of the sun's zenith distance on the electronic concentration of the F2 layer is noticeably different from what is expected, it is the equatorial anomaly. In this area the ionosphere takes on a dome shape. As a result of a combined action between east-west electric fields in the equatorial region and ionospheric winds. We are faced with an injection of electrons from E region to F region. This implies an increase in electron density in the F2 layer. This phenomenon is more intense in the afternoon and early evening. The equatorial dome structure, produces two regions, one to the north and the other to south of the geomagnetic equator, where the ionosphere is systematically tilted and where areas aligned according to the force lines of the Earth's magnetic field are formed which, especially when the geomagnetic field is quiet, we have a higher ionization density than the ordinary F layer and they behave like the walls of a giant waveguide capable of conveying for about 4000 km. (half north and half south of the equator) higher frequency signals than ordinary MUF. For this mechanism, it is necessary that the dome regions located north and south of the equator, they have a sufficiently high degree of ionization. If, for

example, the level of ionization on one side of the equator is not high enough, the wave guide may be unusable. In HF, it is much easier and the margin is greater. Especially in the late afternoon-evening, the HF bands of 17/15 meters, are systematically open on this path. In 6 meters, the situation is much more critical, and the ionosphere is more demanding. The best opportunities are when both hemispheres receive the same solar radiation and this happens during the autumn and spring equinoxes, when the sun is closer above the equator, and then late March and late September. However, the magnetic field is tilted relative to geographic coordinates, as evidenced in the rectangular world map below. In the Western Hemisphere, the magnetic equator is 11° further south of the geographic equator.



The best situation for TEP is quiet geomagnetic field, good weather conditions supported by extensive high-pressure fronts on both sides of the wave guide and during equinox periods. Due to magnetic declination, "the magnetic equinox" occurs about 1 month earlier (February and August) for connections between North and South America. This does not mean much to us in Europe. For stations in North America, on the other hand, it should be considered that even for paths moved east or west, magnetic equinoxes occur before geographical equinoxes, so the date of the magnetic equinox depends on the deviation from the north–south axis of the east-west component of the filed. There is also an interaction between the effect of magnetic equinoxes and the effect of the winter anomaly (which is geographical and not magnetic). For example, if you consider a path between North and South America, it is recorded that partly because of the location of the magnetic equator, MUF are often higher in South America than in North America.

Grey line

To have a good DX propagation in 6 meter band, we must have special conditions capable of raising the MUF, but the margin of the ionospheric layers is critical to produce interesting propagation openings. Another way to have an active ionospheric layer is simply the effect of sunrise and sunset that increases the ionization of F region. On the night side along the terminator, the level of reflection for

a given frequency tends to increase, particle density is low, and collisions are less frequent. So, we have a situation where ionization stays longer without the effect of the sun. On the other side, the illuminated one part of the globe, the action of the sun's rays activates the ions by activating the layers even at low altitudes. The effect is to have two curved layers constantly moving around the earth. Thanks to these ionospheric curved regions, focus phenomena are triggered that affect the signals, also creating phenomena of super propagation such as ionospheric wave guides that hold the signal inside an ionospheric duct, sending it back to the ground a few thousand kilometers away. This phenomenon also known as chordal hop, supports propagation for many of the paths that cross the magnetic equator or along the grey line.

Ionospheric Scatter

Small-scale irregularities and ionospheric ducts are clearly irregularities in the ionosphere which, as is well known, can support propagation in a more complex way than simple ionospheric reflection. In fact, local irregularities can have interesting effects, especially when they occur in large quantities. Long-distance propagation in 6 meter is often the result of several factors. Ionospheric scatter plays a role in many paths, many effects are positive, others negative. To understand how the scatter phenomenon takes place, we must imagine the situation different from the established representation, where the entire horizontal section of the ionosphere contributes to reflection. Ionospheric scatter has a different skip supported by a multitude of normally small reflective or refractive layers. The phenomenon occurs when the signal encounters many cells. This mechanism can be thought as the refraction of an ionized gas bubble, the size of these cells can range from about ten meters to several hundred kilometers. When a wave meets one of these bubbles, it is scattered in all directions. Since the

cells can be found at different distances from the point of transmission or reception, the signal arrives with different paths and therefore with a different phase and since normally the cells move in the ionosphere, a doppler effect is also added. There are two magneto-geographical regions where ionospheric scatter is more common. One in the magnetic tropics and the other near magnetic poles. In the tropics the phenomenon is associated with equatorial anomaly. The strong current moving electrons from E and F1 region to F2 region, this moving, produces huge agglomerations of turbulent plasma that align with magnetic field lines. These agglomerations are composed of a considerable number of plasma cells that produce significant scatter phenomena. In the case of the ionosphere tested by ionosonde to measure the critical frequency, instead of displaying a single layer, the return echoes show a widespread area of echoes that starting from the normal altitudes of the F region extend up to 800 km in height: this condition is known as "Spread F". Scatter supported by the equatorial F spread intensifies seasonally at equinoxes and is canceled when the geomagnetic field is disturbed. We have previously talked about the presence of abnormal layers near the poles like equatorial ionospheric bulges, although the alignment in this case instead of horizontal is positioned vertically along the magnetic field lines. We are also in this case in the presence of scatter regions supported by F spreads, again there is an intensification during the equinoxes with a decay in the summer and winter months. The phenomenon is intensifying in periods of maximum solar activity. The effect is responsible for metal sound modulation that often plagues signals passing through polar areas.

Final considerations

The three basic conditions for good propagation are: ionization, irradiation angle and the presence of ionospheric irregularities, all in the right combination. But

understanding of many ionospheric phenomena is still a long way off, for example we do not know the behavior of medium-scale distortions in F region. The Ionosphere is ideally represented as a completely spherical surface. This is a vision that is very distance from the real situation. In fact, the layers are complex surfaces, subject to solar radiation pressure, crossed by intense winds and ionospheric currents and subject to the influence of weather events in the troposphere. There are several structures of travelling ionospheric disturbances that can cause plasma undulation and produce inclinations that can interact with the irradiation angle and thus reflect signals in transit and locally raise the MUF. Atmospheric gravity waves associated with meteorological phenomena, play a significant role. Solar ultraviolet radiation is the main source of ionization, as a result the sun is the main source of many of these factors. However, the entire scale of factors and especially the way they interact with each other is not known. Daytime variations, solar cycle, solar rotation, flares, equatorial anomaly and a whole variety of weather effects, we know they make their contribution. The predictability of openings remains a dream.

In theory, the best situations for a station located in mid-latitudes are:

Same hemisphere (North-South)
From sunrise to sunset, local winter (November to May in the northern hemisphere), close to solar maximum, during the two-week peak of the 27-day cycle of solar rotation, plus several unknown factors.

Trans-equatorial paths
From sunrise to sunset, October-November and March April, near the solar maximum, the two-week peak of the

27-day solar rotation cycle lasts, plus several unknown factors.

Notes:

1- Atmospheric gravity waves (AGW)

Atmospheric gravity waves are elastic oscillations that propagate into the atmosphere because of its thermal stratification. Wavelengths range from a few hundred meters to hundreds of kilometers, with periods ranging from a few minutes to a few hours. The resulting air oscillations cause small fluctuations in atmospheric variables (pressure, temperature, humidity...) but have a significant impact on the structure of the Ionosphere. In recent years, scientific research on the Ionosphere and radio propagation, has given great prominence to the role of gravity waves and they play a decisive role in the structure of the Ionosphere and therefore in the propagation of radio waves. The AGW, interact with: Sporadic E formation - Tropospheric propagation - influence on F region - Ionospheric disorders - Ionospheric D region absorption - Massing/displacement of ions within the Ionosphere. The influence of AGW. seems more marked in the formation of the night F2 layer, where they would help to provide a small but continuous source of new ionization, contributing to the maintenance of residual night ionization.

2-Meteorology

Recent research on radio propagation is focusing on the influence of meteorology on the ionosphere.

The influence occurs both on a small scale (local variations) for example temporal formations, and on a large scale (global variations), such as El-Nino, jet streams, anticyclones and large areas of high or low pressure. It is likely that several modes of propagation on the 50 MHz and 144 MHz, are induced by the troposphere and weather events except for Aurora and F2.

Propagation in 2 meter band

Troposphere and weather

The troposphere is the lowest layer of the Earth's atmosphere, which at our geographical latitudes extends about 11 km high. All the processes that determine our weather, take place in the troposphere; this is limited superiorly by the tropopause. If the tropospheric air masses are well mixed, the relative temperature and humidity of the air decreases quite regularly, with the increase in height. However, this situation is not often found anywhere on the earth. An interesting difference is manifested, for example, in the presence of high meteorological pressure, which is known to be characterized by beautiful days with little or no wind. In this case the tropospheric air is not mixed, but there is warmer, drier air and therefore lighter air arranged over other cooler, wetter and therefore heavier air. In the contact area between the two air masses, the temperature and humidity vary abruptly. This step is called temperature inversion. These inversions offer interesting possibilities of right-speed connections on VHF. The conditions for the best connections take place with a situation of beautiful weather, warm, anticyclonic weather. Let us see below the various modes of propagation in the troposphere.

Troposphere

The troposphere is the layer of the atmosphere in direct contact with the planet and has the highest percentage of the mass of the entire atmosphere. It is characterized by air density and the average temperature varies vertically by 6 °C per kilometer. The troposphere is home to 80% of the air mass and 99% of all water vapor in the atmosphere. Water vapor plays a leading role in regulating air temperature because it absorbs solar energy and thermal radiation from the planet's surface. The temperature and amount of water vapor decrease rapidly with altitude. The temperature decreases upwards

because the soil is the indirect source of solar heat, and reaches the minimum at -60°C, -70°C, in the tropopause. The concentration of water vapor also varies with latitude. It is maximum at the tropical latitude, where it can exceed 3%, and decreases to the polar regions. All atmospheric phenomena occur within the troposphere; however, turbulence can extend to the lower part of the stratosphere. Troposphere means "mixing region" and is so called because of the vigorous convective motion that occur within it. The upper boundary of the layer varies in height from 8 km at high latitudes to 18 km above the equator. Its height also varies with the seasons, greater in summer and less in winter. A narrow area called the tropopause separates the troposphere from the upper layer, the stratosphere. The air temperature in the tropopause remains constant as the altitude increases.

Refraction of an electromagnetic wave

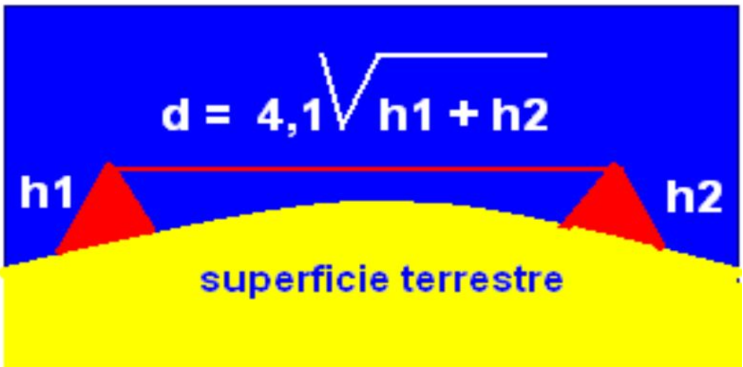
Maxwell's theory says that in the densest medium, light (electromagnetic radiation, behaves similarly to light radiation) slows down its travel and therefore undergoes a deviation, i.e. refraction, because each beam of transverse waves (of which it is composed) varies the wavelength to keep the frequency constant to satisfy the fundamental relationship: *Frequency = speed of light/wavelength.* The ray of light propagating in the densest medium, slows down, and the top of each frontal wave overtakes the lower part, with the result that the beam bends down. The amplitude of this "bend" is directly proportional to the refractive index, which is closely related to the optical density of the medium. The refractive index is a function of the dielectric constant. Electromagnetic radiation, which propagates through the Earth's troposphere, then in a denser medium than vacuum, undergoes a deviation (refraction) on the separation surface between the two means having different dielectric constant, in the same way as light that passing from a less dense medium to a denser medium is diverted. Interpreting Maxwell's

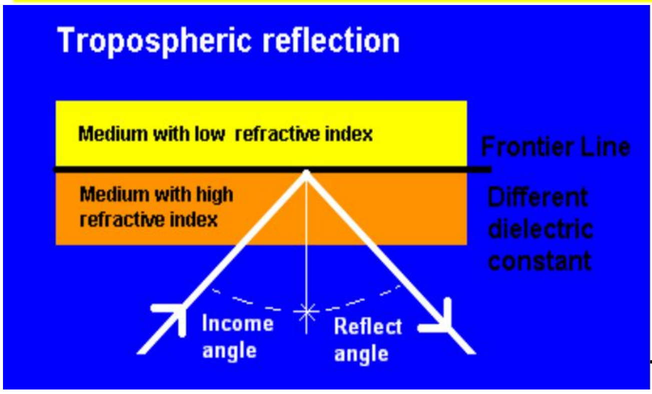
electromagnetic theory, the densest term means, having a major dielectric constant.

Optical range

The connection can take place at any time since the antennas "can be seen". The maximum reachable distance is limited by the Earth's curvature and depends on the height of the antennas of the two correspondents. The optical flow rate can be calculated with the following empirical formula, which also considers the air refractive index (d is expressed in Km and h is expressed in meters):

d=4.1 *h1+h2





The limit of these connections is given by the optical horizon, although the presence of the troposphere improves the theoretical situation, since the air refractive index is greater than 1 (1.00033), and this always causes a certain refraction that can increase the optical distance rate by up to 20%.

Propagation by refraction and tropospheric diffraction

Waves can slightly follow the Earth's curvature by extending the radio horizon. The waves undergo downward bending (refraction) caused by the presence of

layered air masses in regions with different dielectric constants. Coverable distances can be around 100 -150 km. Diffraction is a non-straight propagation of the incident electromagnetic wave on the contour of objects. If there are mountains in the direction of the corresponding station and in the case of a high angle of irradiation that hits the mountain, there may be a diffraction of the signal which, despite many dB of attenuation, can allow good DX communications and which allows to conduct a quite good tropospheric activity in VHF, even at those stations operating for example into the Alpine valleys. Then, there are phenomena of super refraction, such as temperature inversion, which needs a different study.

Temperature inversion propagation

The most common cause of atmospheric refraction is the so-called *thermal inversion.* Normally the temperature in the low atmosphere (100 m. –3000 m.) decreases regularly and steadily as the height increases, if for atmospheric reasons in a certain area, this constant decrease is not respected, that is, the temperature begins to rise again, the phenomenon of temperature inversion, does the normal bending of the waves. The skip distance depends by the height of the inversion, which in exceptional cases can be up to 8 km height, and skip distance depend also by the angle of irradiation of the signals. With an irradiation height of 8 km a skip of about 800 km is therefore obtained, but in practice the heights are lower, so it is rare to reach more than 400 km. The right for inversion is often recognizable by a slow evanescence with little depth. Connections on maritime path are favored by the fact that the sea presents itself as a uniform surface, while on land, apart from natural obstacles, the irregularities of terrain, affect the upper air layers.

Troposcatter

This type of tropospheric propagation is caused by turbulence at the upper limit of the troposphere that generates in continuity miniature inversions, the diffusion

is due to multiple refractions of air agglomerations of different densities, which function as a reflector for signals. To give better the idea, the diffusion (scatter=diffuse irradiation) is composed of simultaneous refractions from many small objects. Tropo-scatter connections are possible at any time even if they require good equipment and antennas, since the attenuation caused by these repeated "bounces" and scattering, is much greater than in normal tropospheric propagation. The distance of the connections depends very much on the equipment, since the signal arriving by diffusion is usually weak, however with an average station, connection of 500-800 and even more km are possible. Signals for tropospheric diffusion are characterized by a strong evanescence, caused by the continuous change of the conditions of the diffusion microcells and by the random paths that can make the reflected signals reaching out of phase to the receiver (distortion).

Tropospheric Duct propagation

In the case of temperature inversion with a large surface, which are formed above the seas, multiple refractions of signals by inversion can take place, and multiple reflections by the Earth's surface, so there is a double or multiple hop propagation. The temperature inversion triggers a drop in the moisture content at altitude (100-1000m.) which determines the formation of the duct. The variation in refractive index is due to the different moisture content in the various layers of air. Radio waves are blocked as if inside a wave guide between an inversion layer and the earth or between two layers of inversion, perfectly following the Earth's curvature, managing to cover considerable distances. In this case there is a weak attenuation of the signal, which is heard at the ends of this "wave guide" and the conditions are good only on small geographical areas. The phenomenon of propagation for tropospheric "Ducting", often occurs, in the warm months, for example between Veneto and Puglia, the ducts are formed above the Adriatic Sea and allow connections of

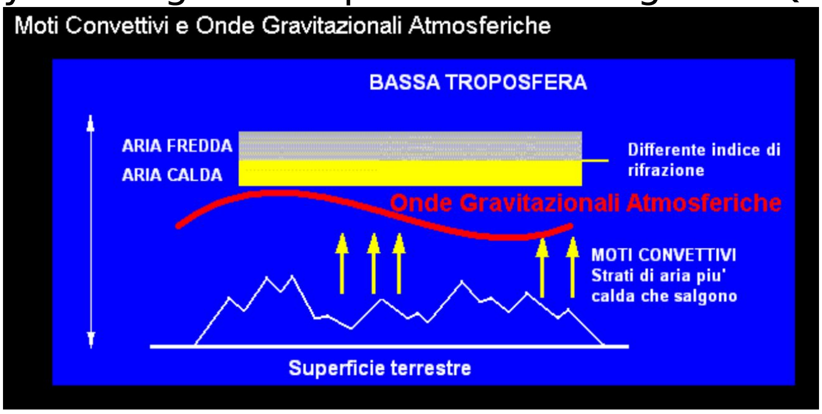
700 - 800 km. In exceptional cases the duct can extend to Greece. Personally, I did several connections between Thiene (Vi) and Puglia region, with extraordinarily strong signals and low power. The same phenomenon also happens in 50 Mhz. Last summer, I listened at the same time of the afternoon, via Adriatic Sea duct, two stations in south Italy, from the Gargano, which transmitted respectively one in 144 MHz and the other on 50 MHz, demonstrating that if the wave guide is present for the 2 meters, it can also be accessible for 6 meters. As already mentioned, in some areas of the earth, especially above the seas, thermal inversions are present continuously, and at very modest heights, in fact the most common area for the formation of tropospheric ducts extends from 100 m up to 1000 m above sea level, they hardly occur at higher altitudes, presumably since rising at altitude the air density decreases progressively, increasingly reducing the likelihood of the tropospheric duct. The weather conditions necessary for these ducts to form are: High barometric pressure (over a large area), good insolation and absence of wind. You can overcome very long distances, 1000 km are not a rarity, the 2000 Km, have been exceeded repeatedly and record connections have been made via ducting, between the coasts of California and the Hawaiian Islands, in the middle of the Pacific Ocean, with a skip of 4000 km, or tropospheric record contact between Cape Verde Islands and Scotland. Furthermore, by using the new digital modes, such as FT8, these distances have increased. Feature of tropospheric ducting propagation is that the two correspondents must be in or near the duct. If the antennas are in an elevated position, and the duct is only a few meters above the ground, the signal cannot enter over the duct. Ducts can only form on flat or low-curvature surfaces.

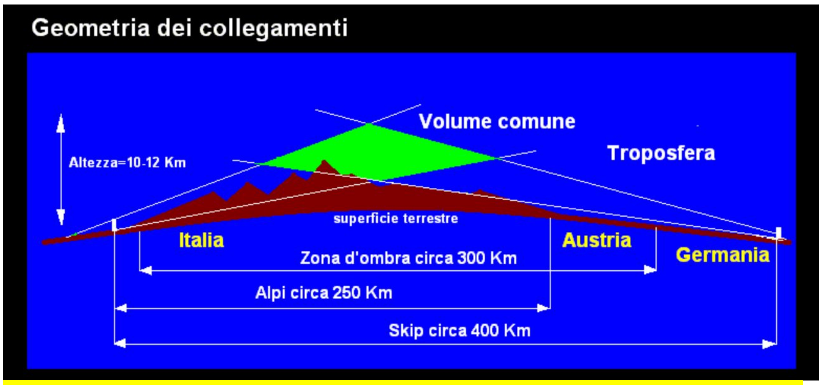
Fig. Photo of a tropospheric duct localized near the Adriatic Sea, due by the daytime sea breeze that, being warmer and wetter, arrived above the earth creeps over the coldest air it finds, creating this layer. Photo by IK3XTV on 04.09.2013 at 18:18 p.m. local time.

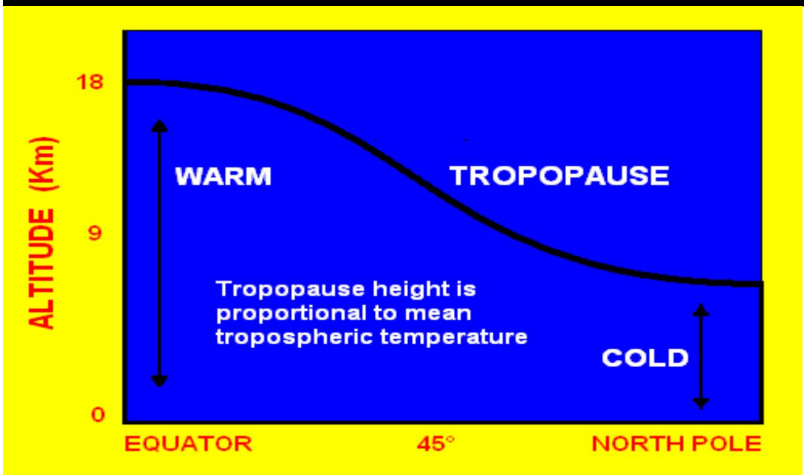
Propagation by convective cells

This way of propagation is like ordinary tropospheric propagation, but which benefits from small local variations in the atmosphere, such as the formation of convective cells, which produce a series of refractions along the path. The contacts between my QTH and the stations located north of the Alps, are to be attributed to this type of propagation. The morphology of the terrain (high mountains and deep valleys) helps the formation of convective cells, responsible for those turbulences and variations in density at air humidity that, as already mentioned, produce a curvature of the radio signal. My hypothesis is that the propagation opening with Germany that I have in my QTH, are due to refraction due to the presence of several convective cells along the path, also favored by the morphology of the earth (high mountains and deep valleys), the rugged nature of the soil, facilitates the formation of cells, which thanks to the irregularities in pressure, humidity and temperature could cause an effective refraction of the radio signal. So, the alignment of

a series of convective cells along the path, would make it possible for the radio signal to spread, allowing it to pass through the Alps and, in other words, could be seen as a train of lenses with reflective capabilities. The effectiveness of this refraction is quite high, although not comparable in terms of signal intensity to "Ducting propagation" since losses along the way can be considerable. In addition, compared to refraction for tropospheric "Ducting", it is much more unstable, and evanescence is much more marked. However, connections are also possible even with small antennas. I also used a five-element log periodic with satisfactory results. Convective cells normally start near the ground and rise about 1 km every 3 hours, so on a summer afternoon, at 3 pm they can be at a height of 3 kilometers. This is the height needed to overcome the mountains and in fact the connections are much easier in the afternoon hours. This type of propagation has been confirmed (though not yet proven) by recent studies by the RSGB Propagation Research Committee. The strong evanescence and instability of the signals is accentuated by my proximity to the mountains (8 km away) which can also cause unwanted reflections, introducing further losses, as you move away from the mountains, you improve the skip and you mitigate the presence of negative QSB.







The radiation of the sun and the Morphology of the territory determine the formation of convective cells

Solar irradiation on the Earth's surface plays a particularly important role in the propagation of VHF signals within the troposphere, because solar radiation causes the warm of air layers. The morphology of the territory decisively influences the conditions of propagation in the troposphere, we know that connections on sea paths are favored not only by the lack of natural obstacles but also by the better tropospheric conditions induced by the masses of water that can form large areas of temperature inversion that can be transformed into tropospheric ducts, within which wave trains can travel with low attenuation. Several factors therefore depend on the shape of the ground, such as: The different distribution of the sun's rays over the various areas of the Earth's surface, the different thermal capacity of the various areas of the earth, the different availability of water vapor, the deviation of moving air masses at the lowest altitudes. Each consequence has a direct impact on the dynamics and

conditions of the atmosphere. Coming to the tropospheric path under consideration, we are in the presence of a mountainous section, with extremely high peaks and deep valleys, therefore difficult to analyze since the morphology of the terrain is complex. However, the presence of deep valleys, seems to favor the formation of cells, because of the different warming of the earth, the formation of convective motions which should be the support of propagation over the Alps. The possible alignment of these convective cells should form a set of lenses capable of carrying signals beyond the Alps. This alignment is not always possible and is not always able to support propagation, confirming the strong instability of signals subject to rapid and sudden evanescence. The stations also arrive strong and then disappear and reappear again after a few minutes. I had ways to discuss with Dr. Volker Grassmann, DF5AI, who was formerly a researcher at the Max Planck Institute (Faculty of Aeronomy) about the various conditions of tropospheric propagation. DF5AI pointed out to me that tropospheric propagation cannot be generalized, but studied in relation to the local morphology of the territory where the connection takes place. Each path has its own characteristics induced by the physical conformation of the territory, that is, by the presence of water masses, valleys and mountain ranges that significantly affect the air movements in the troposphere.

Transalpine contacts analysis

The city of Thiene lies on the extreme edge of the Venetian plain at the foot of the Asiago Plateau. The slopes of the mountains are located about 8 km away and the take off to the north is completely covered. However, connections to stations in southern Germany are quite frequent, although in theoretical way, they are almost impossible. I tried to explain to myself what kind of phenomenon supports propagation on transalpine sector.

Convective cells

The air moves because the Earth's surface is heated unevenly. As the temperature changes, the density of the air varies and therefore the atmospheric pressure, then forces are formed that tend to restore the baric balance, setting the air in motion. As in reality, this is quite complex, because there are many variables that come into play, but in ideal terms it is quite simple. Borrowing the classic example of the pot of water placed on a stove, we will have that the water immediately above the heat source heats up and dilates becomes lighter and leads upwards, resulting in a partial decrease in pressure at the bottom of the central column and an increase in pressure on the surface. In this way, a baric inhomogeneity has been created between the central column, above the stove, and the side walls (cold), so forces are born that tend to restore the altered balance, setting water in motion: from the center to the walls, on the surface, and from the walls towards the center, on the bottom. In this way, we will have what, in technical terms, takes the name of a convective cell. The system described above is even in the atmosphere whenever the circulation system is small (from tens of meters to tens of kilometers as in the case of breezes). In general terms, the motions outlined also characterize the general circulation of the earth's atmosphere, determined by the different insolation between the pole and the equator. On large scales, however, other factors, because of the earth's rotation and the unequal distribution of seas and land that have emerged, become important, thus determining, for example, the formation of the belt of large perennial anticyclones, such as the Anticyclone of the Azores, but also of surface winds like the characteristic “*trade winds*”, discovered by Christopher Columbus. These winds carried his three modest-size sailing vessels across the Atlantic at its widest, from the Canary Islands to the Bahamas, 5400 miles, in 36 days, in 1492. The area most favorable to the establishment of small or medium-scale convective cells are those where the terrain has vast variety by cover and by nature (sea-land breezes), or where the terrain is

particularly rough (valley-mountain breezes), in fact, the variability of slope creates an inhomogeneity of heating because of the different exposure of the soil to the sun' s rays.

Action of Atmospheric Gravity Waves

An important contribution that supports VHF propagation over the Alps, comes from atmospheric gravity waves. Alps mountains generate a series of gravity waves that propagate from the surface to the limits of the troposphere and beyond. The action of the AGW on air bubbles supported by convective motions, would be the cause of the irregularities that cause the refractive index to vary and therefore able to support the propagation of electromagnetic waves.

Troposphere limit

The distance of DX connections, in VHF is influenced by the height of the troposphere, or by the height of that part of the troposphere where the density of the air and consequently of those variations that I have already mentioned, is still sufficient to allow a refraction of the electromagnetic wave. Up to 300 meters above the ground, the air density is uniform, to be reduced to 2/3 at a height of 4000 meters and 1/3 to 9000 meters above the ground. The troposphere contains 90% of the Earth's atmosphere and 99% of the water vapor; it is formed for 21% molecular oxygen (O2), 78% molecular nitrogen (N2) and are present in negligible quantities (1-2%) other gases as well. The area where conditions for effective refraction is in the lower layers of the troposphere. Up to 300 meters high, we find particles of dust, haze, humidity and temperature changes, as you climb the atmosphere becomes increasingly pure and less dense, progressively reducing refractive capabilities. Therefore, the inversion layers (tropospheric ducts) are present up to indicative heights of 1000 meters. To allow 2 meters communications, refraction must take place in a defined area of the troposphere, called the "common volume". In

Tropopause, the temperature is constant (-60 degrees C°), the air density is extremely low and therefore no changes in the refractive index of any kind are possible. In principle, the earth's temperature decreases by about 6 degrees centigrade per 1000 meters of altitude, this is due to the progressive reduction in air density.

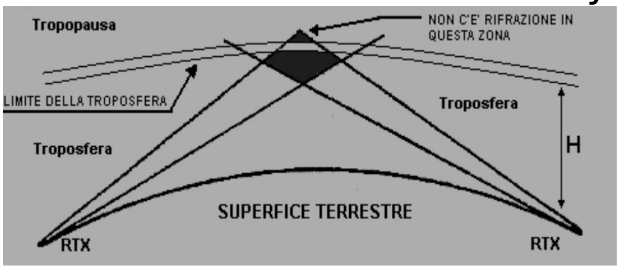
Troposphere height

One reason for the better summer conditions for the DX in VHF, could be the greater refraction for the larger horizon radio, due to the higher humidity of the warmer air and the higher temperature gradient. The height of the troposphere varies depending on the seasons and latitude. This affects the possibilities of our long-distance contacts. Tropopause is the upper limit of the troposphere, which contains diffusion cells capable of spreading (Scatter) our radio signals. The limit of tropopause is therefore the highest point where we can find these cells. One of the reasons for the better propagation conditions of the summer months, may be due to the higher height of the tropopause in summer. Regarding the increase in the radio horizon, it has been calculated that because of heating the air and the water vapor content, the real radius of the earth of 6375 km, can take on a virtual value two and a half times greater, as if it were 16000 km. This means that attenuation on a path can be reduced by as much as 60 dB (1000 times increase in incoming voltage), making a connection more than 300 km away, from impossible to good enough.

Common volume

The common volume is that area in the troposphere where signal refraction can take place, it is a large and indefinite area, that depends, among other things, from the irradiation angles of the antennas, it is linked to the continuous variations and turbulence of the atmosphere however, as already mentioned, can be found at heights up to 3 – 4 km. In this area, intersect the wave beam of the two stations, in a "common" volume of the

troposphere. The height position of this area affects the skip area of communications. This area has as its upper limit in the tropopause. Above this area, there are not any variations and there is not any other refraction.



Fading

Scatter of the signal due to many simultaneous reflections that can arrive out of phase to the receiver, there may be a strong distortion of the signal. To have a good reception it is necessary that all the small signals resulting from the micro-refractories arrive at the stage to the receiver. The slow fading of tropospheric signals is due to changes in refractive conditions in the atmosphere, while rapid fading is caused by the movements of small-scale irregularities that are responsible for the "scatter" process.

Hyper-dense Sporadic E

The Es layer can reach an electronic density level even more than twice the level of the ordinary daytime E layer. Depending on the ionization density of the sporadic E clouds, the frequency that is reflected to the ground varies. Es DX on 144 MHz occurs in 1% of cases where the sporadic E is beneficial for HF frequencies. To raise the MUF beyond 50 MHz, hyper density agglomerates with an extremely high electronic concentration N, are needed and able to reflect wave up to 200 MHz, this happens less time than for example at 50 MHz, where in the summer months, the openings are daily.

The sudden shortening of the skip to 50 MHz, can be a good indicator that sporadic E MUF have risen to the band of 2 meters. But what triggers the sudden increase of MUF? We cannot answer that question. It is only possible to formulate hypotheses such as:

- meteoric ablation
- weather phenomena (thunderstorms)

I would like to follow this last hypothesis, which derives from research conducted by Dr. Volker Grassmann-DF5AI.

And sporadic and the role of thunderstorms in the generation of plasma irregularities

Every year between May and August amateur radio make hundreds of long-distance contacts (800-3,500 km) in 144 MHz All these communications are possible thanks to irregularities in ionospheric plasma at the height of region E, called sporadic E. There are therefore single and sometimes double-skip connections. Occasionally strong thunderstorms occur near the center (point of reflection) of the paths of radio contacts The hypothesis is that thunderstorms are a possible source of trigger for sporadic E, especially for the most intense phenomena, responsible for raising the MUF above 144 MHz This hypothesis, however, is not entirely accepted by the international radio amateur community since the effect of thunderstorms on the formation of sporadic E has not yet been demonstrated with scientific conviction, although there are many scientific studies underway on this topic. I would like to bring only my field experience on this hypothesis. In the following pages, dedicated to sporadic E, I would like to talk about some studies I have done to analyze this phenomenon.

Effects connected to the sprites

These phenomena are like lightning that develop in the stratosphere at a height between 10 and 100 kilometers, so electric discharges occur lasting a few tenths of a second that develop due to the difference in potential between the clouds and the high atmosphere. These events are of interest to E region and could have a significant impact on the structure of the ionosphere.

Fig. Vertical development of a Sprite. The discharge propagates from the troposphere up to a height of 100 kilometers, directly involving the Ionosphere (D region D and E region. The largest events have a diameter up to 100 km and can propagate in a volume of 10000 cubic kilometers.

Discussion

During June, a high activity of sporadic E and spherical is common; and it is no surprise that both can occur in the same geographic location. In this case, however, the sporadic E and the position of the spherical, shows a similar space-time distribution. These results show that the convective effects of a thunderstorm by generating gravitational waves propagating from the low atmosphere to the upper atmosphere stimulate Es formation. Is it possible that this result indicates a dynamic process at mid-latitudes like what happens in the tropical atmosphere where some phenomena such as TID (Traveling ionospheric disturbance) and equatorial F spread are really caused by the convective motions of thunderstorms? We cannot answer this question now because the data collected is not yet enough and it is not even possible to rule out a random result altogether. However, we believe that these results are the reason for further and more in-depth studies and the reason for closer collaboration between scientific experts and radio amateurs operating

on VHF (like what happened in the 60s and 70s with aurora research). Observations by amateur radios can only detect the presence of Es's propagation and the simultaneous presence of thunderstorms. On the other hand, scientific data are necessary to analyze the phenomenon in detail, for example with the use of ionospheric and ionosonde radars in the central European area.

Sporadic double jump E propagation

HYPOTHESIS: The reflection on the ground in the center of the path could be supported by important waterways, as analyzed for a series of QSO between the Canary Islands and Germany. In fact, by extrapolating the data of both stations it is possible to establish the median point of reflection. The Earth's surface is a poor reflector of VHF signals. When there is water (an ocean or a large lake) at the midway point of reflection, the reflection is much more efficient. This is even more true from the analysis of some QSO made by my friend Volker, DF5AI, where it is evident that terrestrial reflection at the mid-point is supported by some important waterways. In fact, in the figure below, there are highlights a series of contacts between the Canary Islands and Germany, where the mid-point coincides with a geographical area in Extremadura – Spain, this area is rich of rivers. This discussion focuses on the geographical location of reflections on the ground, many other observations seem related to the location of important lakes or rivers that can support a reflection of the incident wave. However, the concept of reflection across lakes and rivers must be considered as a speculation that is supported by many examples, even if a final check is not yet available. Although this phenomenon really exists, it cannot explain all cases of double-jump ES propagation. In some cases, the reflections are related to the position of the rails of the railway lines. The reflective capacity of the earth varies from excellent to extremely poor. It depends on geographical location: salt water has a dielectric constant K=81 and a conductivity G=5 S/m,

agricultural or forested area have a dielectric constant K=13 and G=0.006 S/m while urban and industrial areas have a K=3 and G= 0.001S/m.

Trans equatorial propagation (TEP) on 144 MHz

Trans equatorial propagation is based on the reflection of radio waves in the ionospheric F2 region that extends from 250 to 500 km above sea level. This layer does not reflect VHF signals, and even 50 MHz are reflected at certain favorable times and during periods of high solar activity. Why are 144 MHz connections possible in certain circumstances between stations located at about the same latitude but in opposite hemispheres?

The maximum frequency reflected by the F2 region depends on the combination of several factors:

- Ionization density present.
- The angle of irradiation of the signal in the ionosphere.
- The presence of irregularities in ionization.
- Single-jump connections are not possible in 144 MHz because ionization is never high enough to allow a signal to exceed the horizon to reach the F2 layer at an angle of incidence so small that it is reflected.

A explanation for the phenomenon is the presence of many irregularities that together with high ionizations and low incident angles, allow the signal to be reflected to the ground instead of getting lost in space. An anomaly that undoubtedly influences the mechanism is the equatorial anomaly, an ionospheric curvature straddling the geomagnetic equator, where for 20° to the north and south (it means a belt about 4000 km wide), the ionosphere has a dome development. This structure has two regions, one to the north and the other south of the equator where the ionosphere is tilted upwards. The curvature causes the signal to arrive at a lower and enough angle of attack and divert it to the opposite hemisphere where it is reflected to the ground. In this curved ionospheric region, a giant wave guide is created

under certain circumstances that can support the signal propagation for thousands of kilometers.

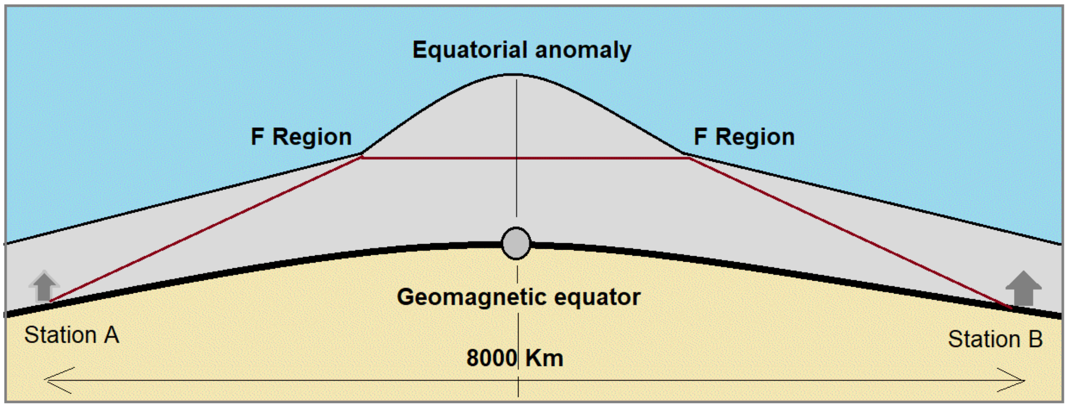


Fig. Equatorial anomaly: For the TEP mechanism, we need high ionization in both sides of the curved ionospheric region. At 144 MHz the ionosphere is very demanding and critical, so favorable conditions that can support openings are rare. F Layer must have a high residual ionization base, and this occurs during the maximum phase of the solar cycle. In addition, hemispheres must be equally illuminated by the sun (equinox periods) with good weather conditions, corresponding to extensive high-pressure fronts on both sides of the equator. In the figure the path of the signal is illustrated in summary: The first reflection takes place in the F region at more than 2000 km. from the transmitter. On the 144 MHz, thanks to the high-gain and ground-based directional antennas, it is possible to obtain very low irradiation angles and therefore for a simple trigonometric effect it is possible to obtain much longer jump distances than the HF bands.

Ionosphere behavior in VHF

Influence of the ionosphere at VHF	100MHz 200MHz
Change of phase path length	-400m -100m
Change of group path length	+400m +100m
Refraction	0.02deg 0.005deg
Phase change	-48000deg -24000deg
Frequency shift	6Hz - 3Hz
Time shift	1.3microsec - 0.3microsec
Polarization rotation	380deg - 95deg
Absorption	0.05dB - 0.012dB

Below is a table showing the behavior of the ionosphere in VHF. The data refer to a signal that passes only one time inside the ionosphere and radiates at an angle of 90°. As a result of physiological plasma variations (solar activity, geographical location, time) the data may vary by a factor of +/- 10.

Reflection by plane
Airplane scattering (or most often reflection) is observed on radio waves from HF to VHF, through to microwaves. Compared to a single trail of meteor scatter, the time of opening caused by a single airplane is longer, it can be from 30 seconds up to a few minutes. Slight asymmetry can sometimes be encountered both in terms of exact timing and the gain of the path. Range and contact lengths are affected by the size of the plane, flight height level and the approximate crossing time of the central part of the straight line between the two communicating stations.
Both the onset and decay of the communication is rapid, so to improve success rate, a short contact procedure is used, like Meteor scatter.

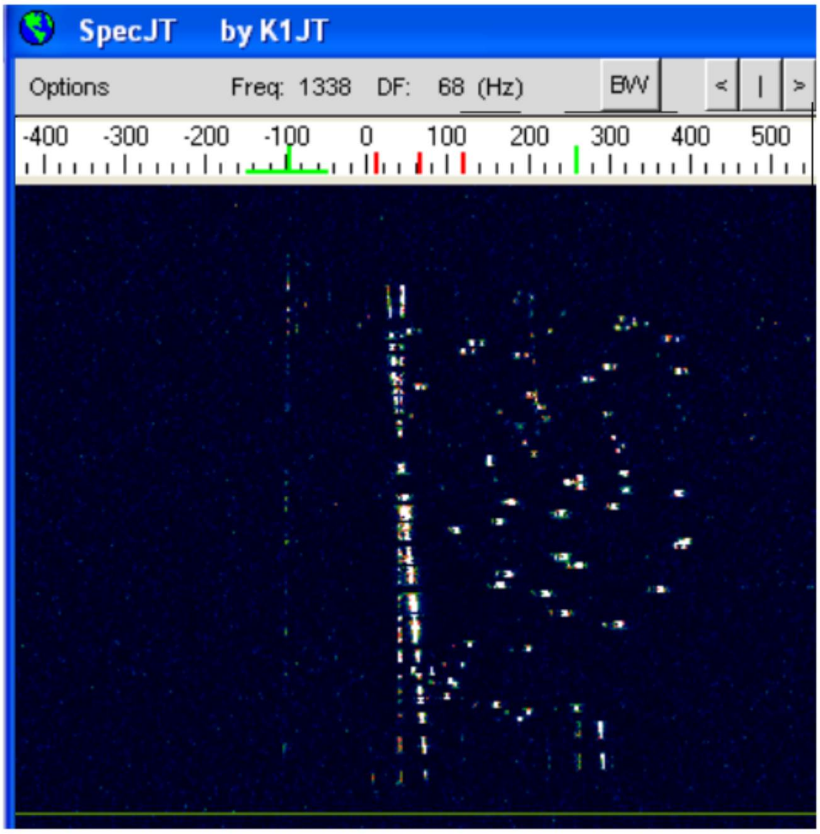


Fig. JT65A transmission of the station from Slovenia S52LM. On the left you can see the weak trace received via EME from S52LM. Just at the right of the EME trace, there is the signal received via troposphere. overlap on the tropospheric trace, you can see an oblique track with doppler effect. It is an airplane reflection from a plane flying over my area and coming towards me. In fact, if the doppler is positive, the airplane flying in my direction, while if the doppler is negative it moves away. The doppler is a few Hz. I remember that the horizontal axis stands for the frequency and the vertical axis represents the time.

An Interesting analogy with optics: Refraction and diffusion phenomena

We will see later in this book, that a radio wave does not differ in any way from an optical wave except for the wavelength and therefore the frequency. Both units are in fact related to the constant C (speed of light), if lambda increases, the frequency F must decrease. Thanks to Marco Melotti who gave me his permission to publish the wonderful image taken with a simple Reflex, from his Bocca di Selva mountain hut, at 1550 meters above sea level, in the Mount Carega group, in province of Verona. This is the Monviso, with its characteristic pyramid shape also known as the "Stone Giant". Seeing it so clear does not happen so often, but every now and then it happens. Because this happens, you need an exceptionally clean, moisture-free atmosphere. These conditions can be when the Föhn blows, the warm wind that descends from the Alps. The characteristic of the Föhn is that it is a wind with extraordinarily little humidity. When the Föhn has sufficient strength to reach the Po valley, it cleans the valley from the clouds and dries it. We therefore have excellent visibility conditions, especially in the evening, looking towards west, where the Monviso is found, when the sun setting on that side and stands out the silhouette of the Mountain against the light, highlighting its shape in a well-defined way. It is a phenomenon of focusing that, although in a different way, can happen for electromagnetic waves. I calculated that the distance in a straight line between Bocca di Selva hut and the Monviso is 330Km.

Fig. Image taken by Marco Melotti, after sunset, when the low light accentuates the contrasts and makes distant objects more visible.

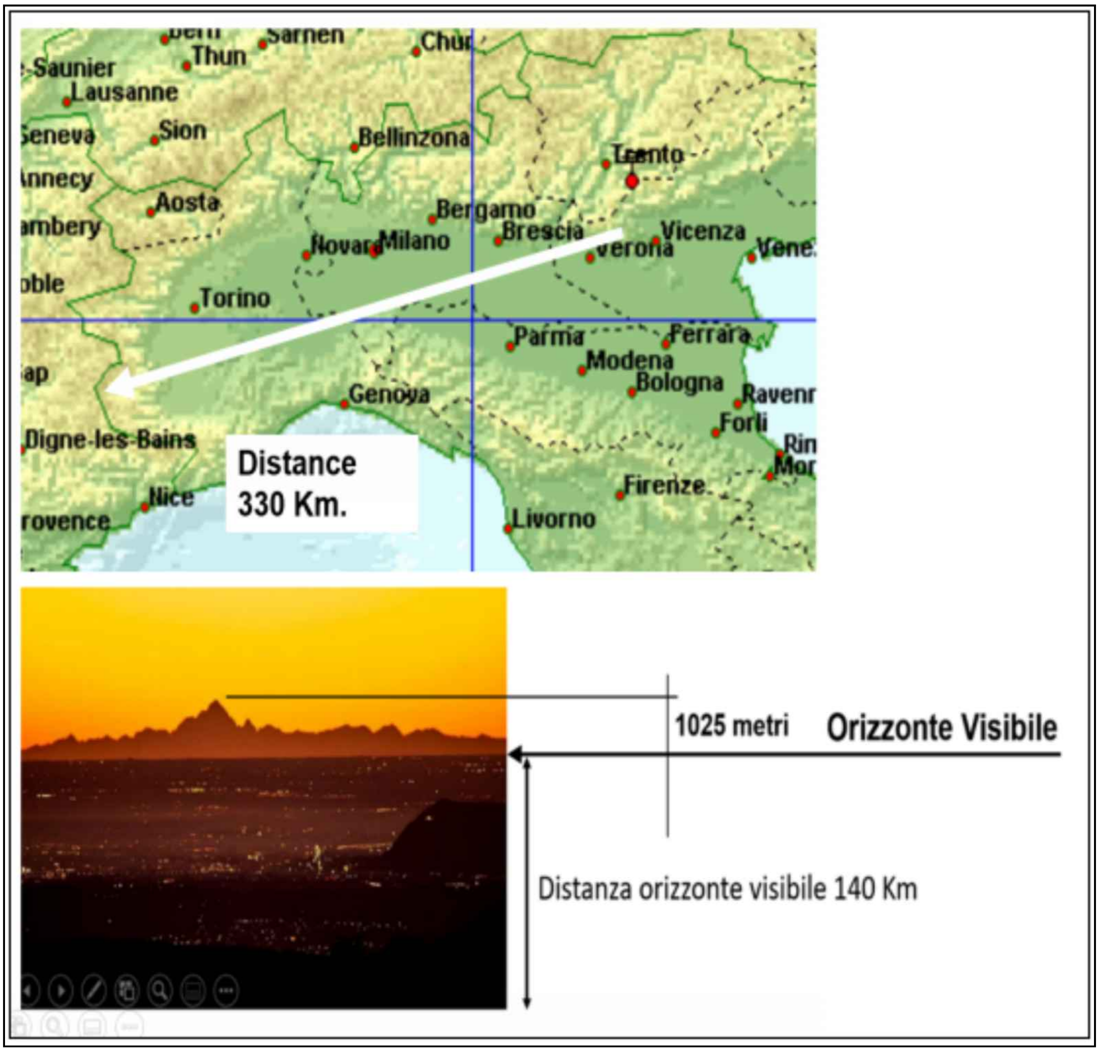


Fig. The distance in a straight line is 330 Km. The Monviso has a height of 3841 meters. Due to the curvature of the earth, the non-visible part of the mountain, is 2816 meters, so the visible part in the photo is 1025 meters. The distance of the optical horizon from the observation point is 140 Km. The part of the Po Valley visible in the image extends up to the area between Milan, Pavia and Piacenza. (Map created with Google Maps).

Troposcatter over the Alps

Study of VHF propagation with WSJT digital transmission – JT65 mode

Introduction

This paragraph describes a communication experiment beyond the Alps, in 144MHz.
This type of VHF propagation is also called "Knife-edge", due to the refraction of the ground and the edges of the mountains. It is possible overtakes the Alps in VHF, even with low power, less of 2 watts. Tropospheric irregularities added with diffraction signals on alpine peaks, which can support propagation with a good regularity, even with poor propagation conditions. This is multiple diffraction propagation that can propagate the signal beyond the shadow zone. In addition, radio waves, thanks to this form of diffraction, follow the Earth's curvature for several hundred kilometers through the troposphere. I used WSJT digital mode, because it is a suitable software for propagation studies. You can work with very weak signals but you can see the signal and visualize the time and frequency of the signal spectrum received in real time.

Troposcatter

This type of tropospheric propagation is supported by turbulence found at the upper limit of the troposphere. Scatter is due to multiple air refractive agglomerations of different densities, to give a better idea, scatter (diffuse dispersion radiation) consists of simultaneous refraction by many small particles such as air bubbles. When the wave passes through the troposphere it meets turbulence, it produces a rapid change in speed. This causes some energy to be spread forward and bent to the ground at distances beyond the horizon. Tropo-scatter connections are possible at any time even if they need extremely sensitive equipment and high gain antenna system because the attenuation caused by these repeated "bounces" and scatters, is higher than normal tropospheric propagation. The air is not uniform, there are vortexes, ascensional thermal currents and turbulence. Where the air has a slightly different pressure, there is a different refractive index. Vortexes vary in size from 100 m to 1 mm. The energy that is fed into a turbulent system goes into larger vortexes and smaller vortexes are eliminated from them. This process continues until the scale of turbulence is small enough to make viscous action and dissipation important as heat occurs. The maximum distance reached depends heavily on the equipment (output TX power) and from the antenna system. Troposcatter signals are characterized by a strong fading, caused by the continuous changing conditions of the diffusion microcells and random paths that can bring out of the phase (distortion) reflected signals that reach the receiver.

Diffraction

Diffraction is a physical phenomenon associated with the deviation of the trajectory of waves. This is a deviation of the propagation trajectory of waves when they meet an obstacle in their path. Diffraction occurs when the wave passes over something that hinders its path. It is possible that radio waves are bent slightly (and therefore diffracted) even above edges or edges and can be diverted when lapping the edges or corners of any type of Obstruction. This is known as "Knife Edge" diffraction, which occurs on VHF, UHF. Thanks to the diffraction, the signal manages to overcome even in what would be the shadow zone behind the obstacle.

Ground diffraction

Ground diffraction plays a key role in communications beyond the horizon in VHF. Diffraction is most important when there is a common edge (such as the summit of the mountain) on the horizon, found close between the two stations that must connect with each other. Under the right conditions, diffraction may occur on multiple consecutive edges. In addition, during periods with high variation in the refractive index, the radio horizon may increase, to lower the irradiation angles. The Alpine path should be significantly influenced by this phenomenon. For those stations that are located at the foot of the mountains and have low irradiation angles, even in super refractive conditions, the waves must suffer a diffraction around different edges, (i.e., the mountain peaks) and in this way they are able to overcome the obstacle.

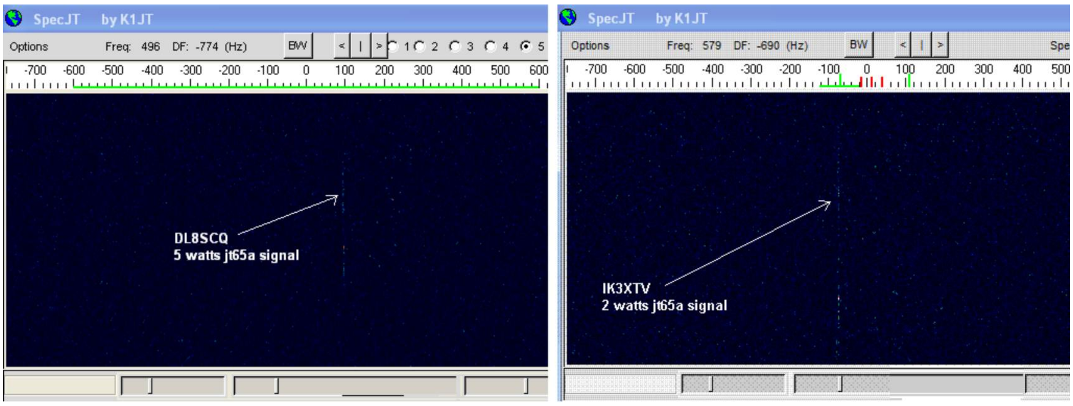


Fig. In these figures, you can see on the left the JT65A signal transmitted from DL8SCQ with 5 W and received by IK3XTV, while on the right you can see the signal transmitted by IK3XTV with 2W and received by DL8SCQ. The distance between the two stations is 387 km. and both are found at the foot of the mountains, on both sides of the Alps. DL8SCQ is in Allmersbach near Stuttgart, southern Germany. For both stations, antennas were 2 Yagi with 8 horizontally coupled elements.

Fig. Map of the skip between IK3XTV and DL8SCQ. The weather in the southern part of the Alps was cloudy with rain, while there was high pressure and clear, sunny skies in the north side of the Alps, as reported by meteo satellite. Map created using the DX Atlas software, www.dxatlas.com.

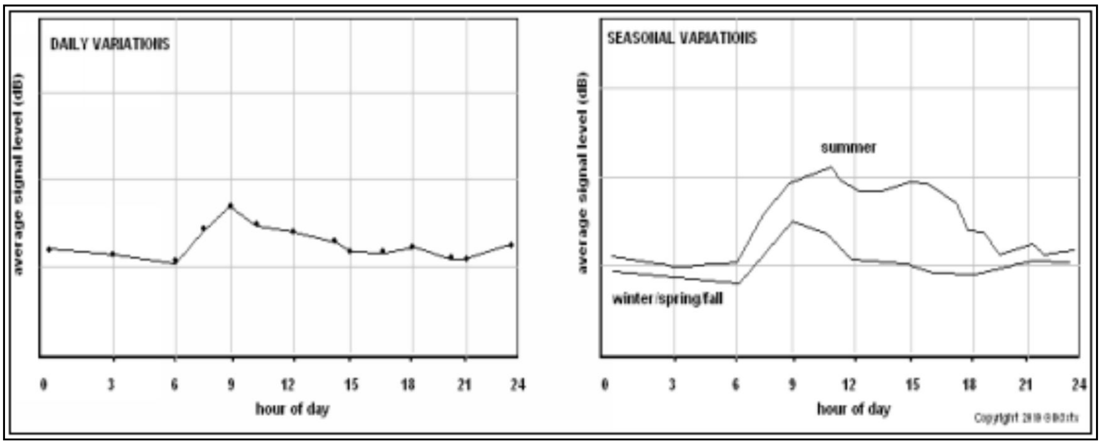


Fig. The graphs show the summary result of troposcatter research and report the average signal level over the course of a day and during the year. The graphs derive from the interpretation of many QSO data on VHF and mediated to realize an indicative diagram of the level of troposcatter propagation. The difference between day and night hours is due to significant changes in air temperature.

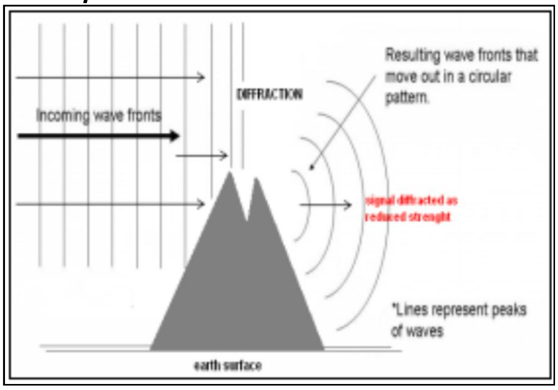
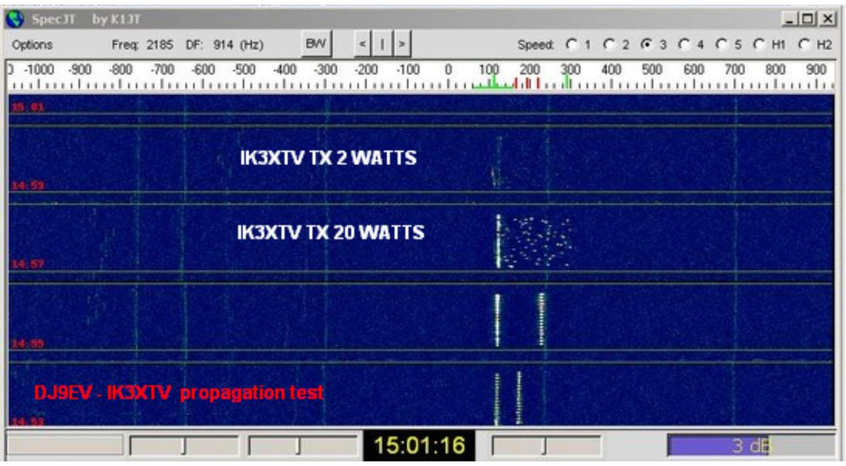


Fig. Left: The figure shows the basic principle of electromagnetic wave diffraction: "Knife Edge diffraction". For multiple diffraction, that is, for what happens in realities, there is a series of many consecutive diffractions. The longest transalpine QSO, I did with DF2ZC, located in Breitscheid south of Bonn. In this case, using the high EME power. The path was 618 km, with about 200 km of diffraction and more than 400 km of troposcatter section.

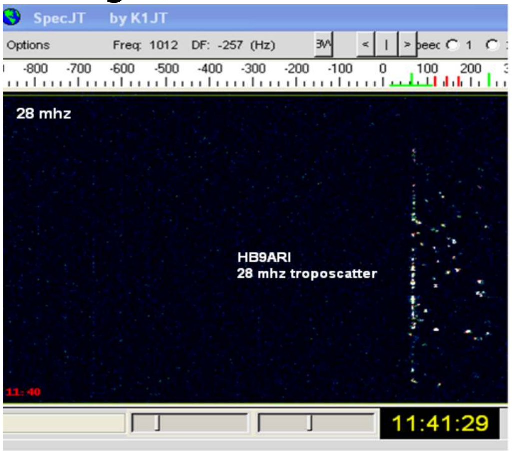
Improving propagation from snowy ground

Some experiments show an improvement in propagation when the diffraction section above the Alps is covered by snow. This may be since diffraction is more efficient and diffraction losses are lower (diffraction coefficient is better). The signals are less plagued by fading, both fast and slow, than experiments done in the summer, with mountains without snow.



Troposcatter experiment in 10 meters

Also, with WSJT, I did some tropospheric propagation experiments in the 10 meter band. These experiments have confirmed that troposcatter in the Alps is also possible on this frequency. More power is needed, because the antennas have a significantly lower gain, but also because the air bubbles in the signal scatter have too little amplitude to support refraction over wavelengths of 10 meters and diffraction on the mountain obstacle absorbs more energy. The signal is plagued by rapid fading. (HB9ARI test near Neuchatel, Switzerland).



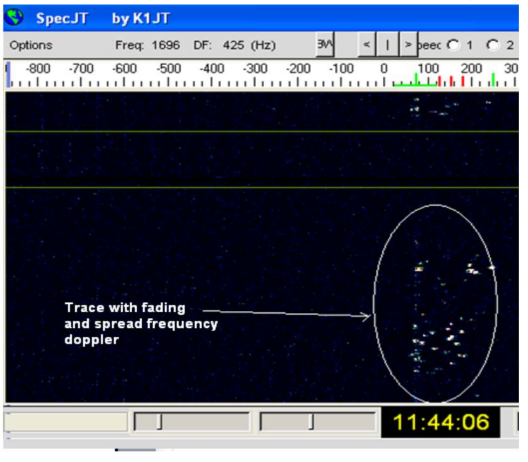


Fig. Experiment of tropospheric communication with the Swiss station HB9ARI, in the 10 meter band with JT65A. The figure shows the spectrum of the signal I received from HB9ARI. In the right panel you can also see the track with fading and frequency doppler (an enlargement of signal frequency).

Interference causes reflection and diffraction

The ground around an antenna plays a significant role in its signal quality. If there are obstacles around the antenna, the emitted waves will bounce over them in a similar way to the reflections of visible light, as there is an angle of incidence and a reflection angle. In the figure below, I illustrated an example of the tropospheric path from a transmitter, Tx, to a receiver Rx, (red line, main signal) and two reflection paths (black line) with diffraction on an obstacle. There are countless reflections, but we will see two.

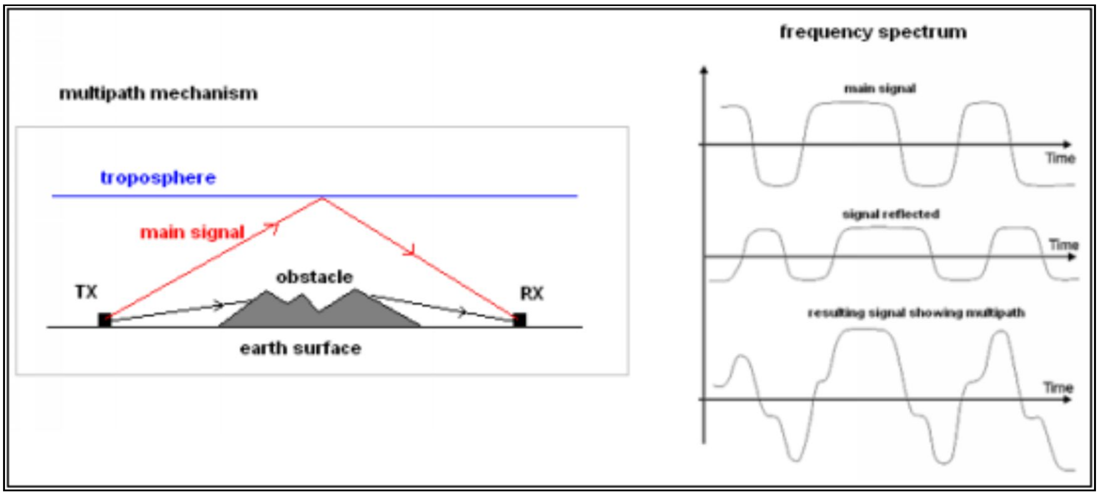
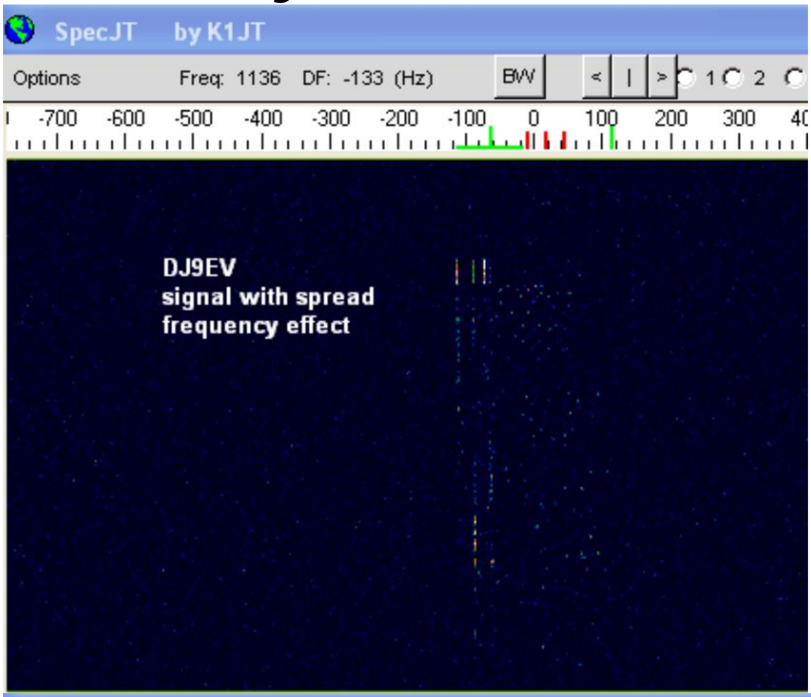


Fig. left side: Multipath mechanism. Right side: Received signals, i.e., main signal and reflex signal and below the graph of the combined sum of the two signals. Main signal + reflected signal.



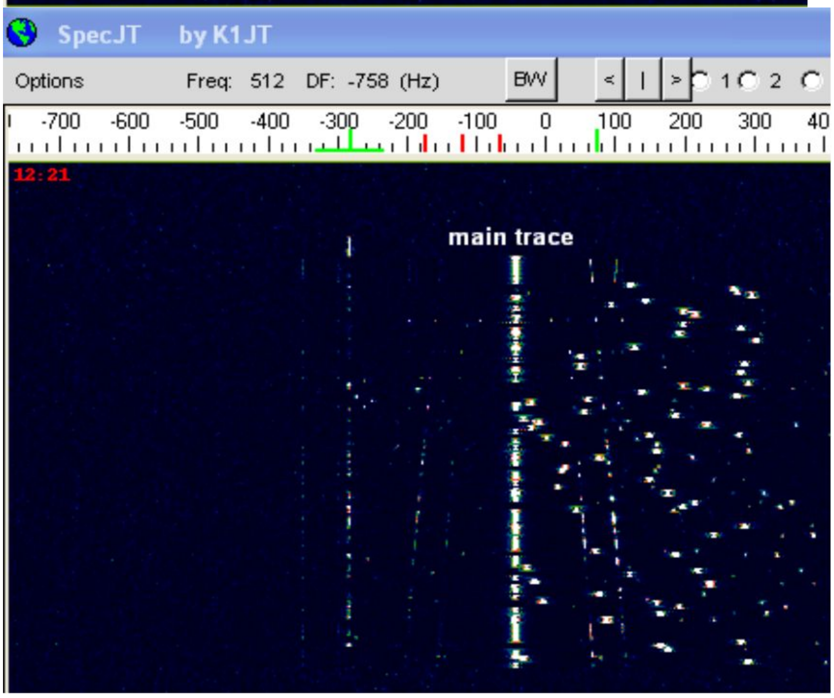


Fig. The left Image shows another experiment with low-power communications over the Alps with the German station DJ9EV. It is Interesting to observe the frequency spread. Right image: Strong signal transmitted from a local station near my station, where multipath propagation effects are seen, with a main track and other secondary tracks coming from difference path reflections (multipath) and doppler effect with frequency drift due to reflections by airplanes.

Reflections

To better understand the figure below on the previous page, which shows the combined sum of the main signal + reflected signal, we need to better understand its propagation mechanism. The first thing you can notice about the signals received is their phase shift; this can be easily explained. The electromagnetic waves travel at the same speed, about the speed of light or 3x10^8 m/s, but their distance traveled from Tx to Rx is different. First, let the corresponding distances for line 1, line 2, be d1, d2. Then we know that their corresponding delays would be t1 = d1/c and t2 = d2/c, where c is the speed of light. Now we know when they get there, but we can also notice that there is a difference in amplitudes between the multipath signals received. From the basic theory of electromagnetic waves, we know that signal strength decreases with distance, but in this case, it is not so because the distance difference is not large enough to cause it. In this case we must make use of the physical theory of reflection of light. When an EM wave is reflected by an object, some energy is transmitted to the material of the object and the rest is reflected. The coefficient of reflection depends on the material. In addition to reflection, diffraction can also be a cause of reduced signal strength. For example, diffraction due to a peak or edge of a mountain. A peak or edge like the one depicted, reduces signal strength in the area beyond the visible horizon, but since it is a form of radiation and diffraction, it is possible that there is a contact but at a very weak signal level.

Selective frequency fade

In any radio transmission, the spectral response of the channel is not flat. It has spikes or evanescencies in the response due to reflections that cause certain frequencies to be erased at the receiver. Reflections on nearby objects (e.g., land, buildings, trees) can lead to multipath signals of signal strength like the direct signal. This can cause deep cancellations in the signal strength received due to destructive interference. For narrow-bandwidth transmissions if a null in the frequency response occurs at the transmission frequency, the entire signal can be lost. The original signal is distributed over a wide bandwidth and therefore nulls in the spectrum are likely to affect only a small number of vectors rather than the entire signal. Information in lost vectors can be retrieved using error correction techniques. Often the signals are plagued by an enlargement of the frequency and scintillation spectrum (frequency diffusion) this is explained very well by applying a theory formulated by Rumsey (University of California - San Diego). Explains how this scintillation depends on a floating space-time refractive index of the medium located between the source (transmitter) and the observer (receiver). A small variation is enough to produce the phenomenon, especially when there is a change in the refractive index in space of a wavelength.

Delays and errors

The radio signal received by a transmitter typically consists of a direct signal, as well as other signals reflected on objects such as buildings, supports, and other structures. The reflected signals come arrive later than the direct signal due to the extra length of the path, giving rise to slightly different arrival delays, spreading the energy received over time. The spread of the delay is the time between the arrival of the first and last significant multipath signal, seen by the receiver. In a digital system, the spread of delay can lead to interference between symbols and thus to create decoding problems. This is due to the delayed multipath signal that overlaps the direct signal by creating an overlap of the information contained in the message (numbers or letters in the case of digital transmission). To work around this problem, in the jt65 digital transmission protocol there is a solid error correction scheme that can overcome this problem.

Hypothesis

In the following table there is the calculation of the path loss of free space of a 144 MHz signal transmitted with 2 watts of power and refers to my experiment with the German station DL8SCQ, using the theoretical equation. The level of signal strength received is expected at 0.08 microVolts. I cannot calculate the resulting power level, after several diffraction effects and troposcatter. The resulting power level is certainly much lower. Just think of the enormous energy absorbed during these processes. The result is an extremely weak incoming signal. Despite the excellent ability of WSJT software to extract weak signals from noise, the resulting signal is too low to reach the receiver. Although I realize that it could be very abnormal and unorthodox, I think a hypothesis: There may be some sort of automatic amplification in the tropospheric propagation/atmosphere process, as well as a focusing effect or slow effect on signals as is sometimes the case for visible light? It must be thought that visible light is always an electromagnetic radiation involving the movement of photons / electrons in the middle.

Free space path loss calculation

Distance to Transmitter : 387.00 kilometers
Transmitter Frequency : 144.0000 MHz (0.1440 GHz)
Transmitter Power : 2.00 Watts (33.01 dBm)
Transmitter Antenna Gain : 17.15 dBi (15.00 dBd)
Receiver Antenna Gain : 17.15 dBi (15.00 dBd)

Received Power Level : -128.66 dBm (0.08 μVolts)
Free Space Attenuation : 127.37 dB

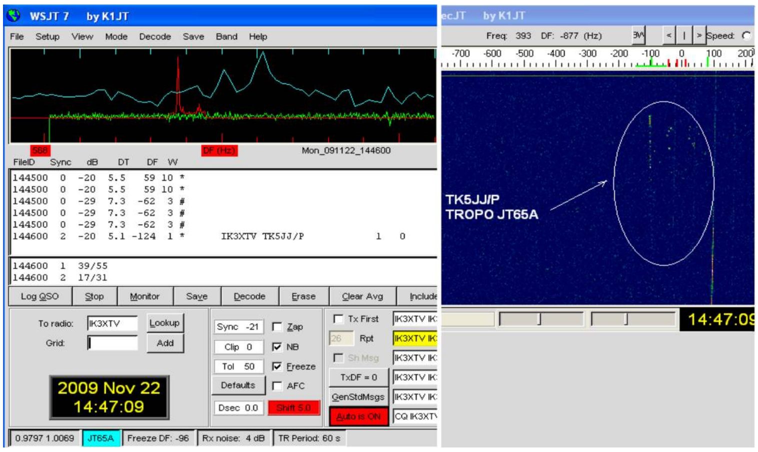
I thank the following Radio amateurs with whom I have conducted tests in VHF:
DL8SCQ, HB9ARI, HB9CAT, DJ9EV, OE3FVU, DF2ZC, DG6MAN, DL8GAP, OE8HBQ, OE3WMA, OK1MDK, DF2ZC

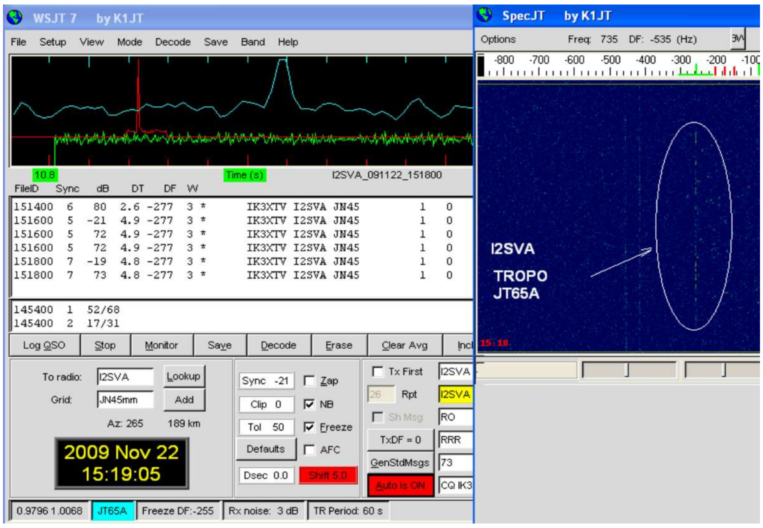
Troposphere experiments in 144 MHz band with WSJT - JT65A.

Joe Taylor's WSJT program lends itself very well to experiments on tropospheric propagation in the 144 MHz band. The experiments were conducted with a simple directive antenna 5 elements Log periodic and a maximum transmission power of 100 watt. The first contact was with I2SVA, from Como, taking advantage of a reflection (scatter) on the Emilian Tuscan Apennines. I did Another QSO with the station TK5JJ/P, from Ajaccio - Corsica, in this case pointing the antennas directly along the same geodesic line and just to cross the Apennines.

Troposphere variability

Another QSO near the limit, was with IT9CJC, from Ragusa with a skip of over 1000 km, far to the limit as the tropospheric conditions on such long path vary very quickly. The connection was possible thanks to the EME station di IT9CJC (4 X 10 Yagi elements). However, there is a great tropospheric variability along long paths, in fact the longer the path, the more variable the conditions are, and they are related to the movements of air masses in the troposphere.





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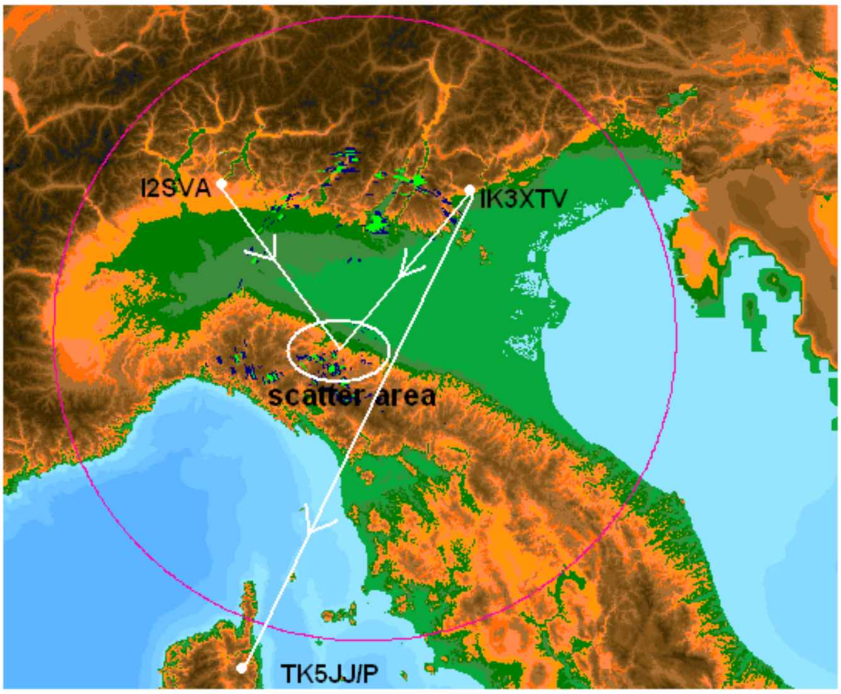
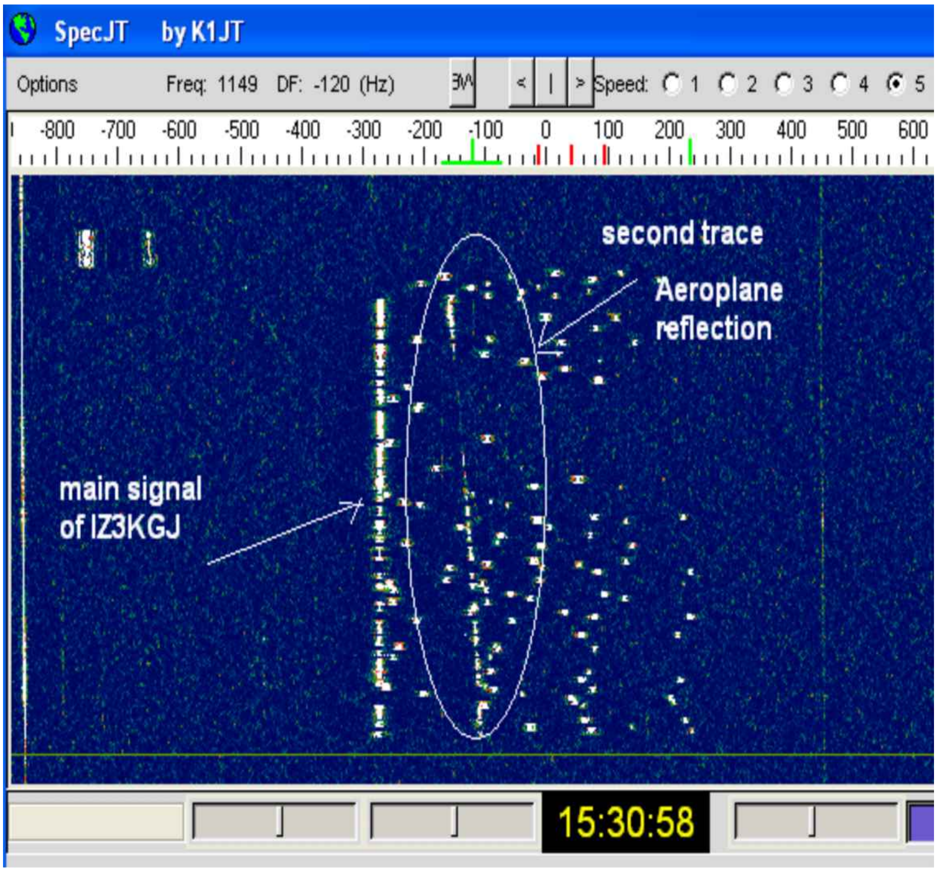


Fig. Diagram of the contact with I2SVA in Como, with reflection on the Apennines and diagram of contact with TK5JJ/P in Corsica.

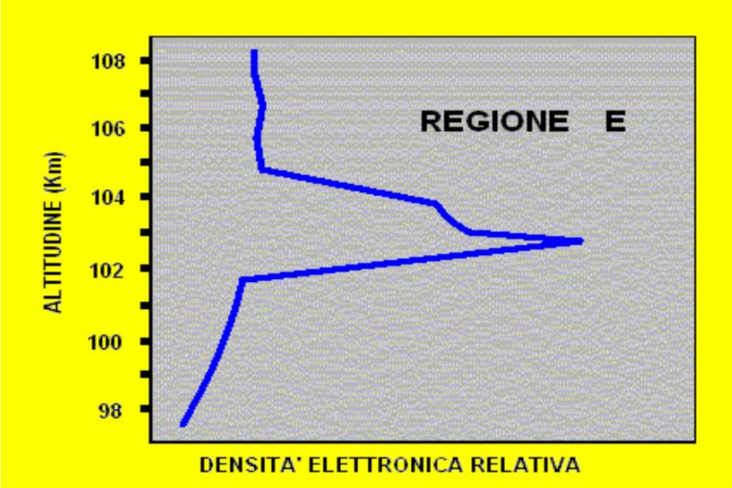
Anomalous reflections
Often double traces occur due to reflections from mountains or other surfaces, the phenomenon is more evident for those who are near the mountains. Traces characterized by doppler effect with consequent aerial reflection also occur, as evidenced in the figure below where double beams are visible caused by these reflections. In this case it is the trace of IZ3KGJ that was calling via EME.



Sporadic E layer formation

Introduction

The phenomenon of sporadic E propagation is one of the most fascinating ways of propagation, but at the same time also one of the most unpredictable events and difficult for science to understand. It involves the upper part of the HF spectrum and in extreme cases it also involves VHF bands up to frequencies of 200 Mhz. Sporadic E is particularly evident in periods from May to September especially during daylight hours (4 hours after sunrise) or during the early evening hours (especially on 50 MHz), and there is also a slight recovery in December.



The coverable distances depend on the height of the layer and the vertical irradiation angle of the antenna, and in any case the skip distance range from 1000 to 2500 kilometers, with reflections of a single jump, but in exceptional cases there may be two-jump reflections that increase the distance up to 4000 kilometers, while multiple-jump reflection is not known since the extensive and simultaneous presence of sporadic E clouds on a large geographical scale is unlikely. The discovery of this type of propagation dates to the 1930s, when Prof. Edward J. Appleton, (Nobel prize in 1947 for his important research on ionospheric layers) noted the existence of a highly ionized and anomalous stratification at the height of the E region, which he later called *"Sporadic E" or Es* by the fact that the phenomenon occurs sporadically. This chapter does not want to be a manual, it is a study based on observations and practical experience, specific research about the events and exchanges of ideas and opinions with other radio amateurs.

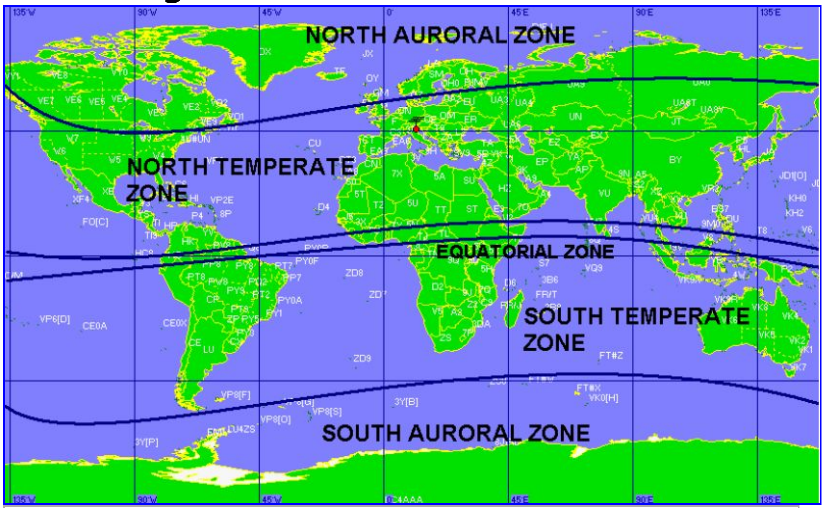
Figure *Relative electronic density due to the presence of sporadic E within E region. The electron density reaches values like those of F layer.*

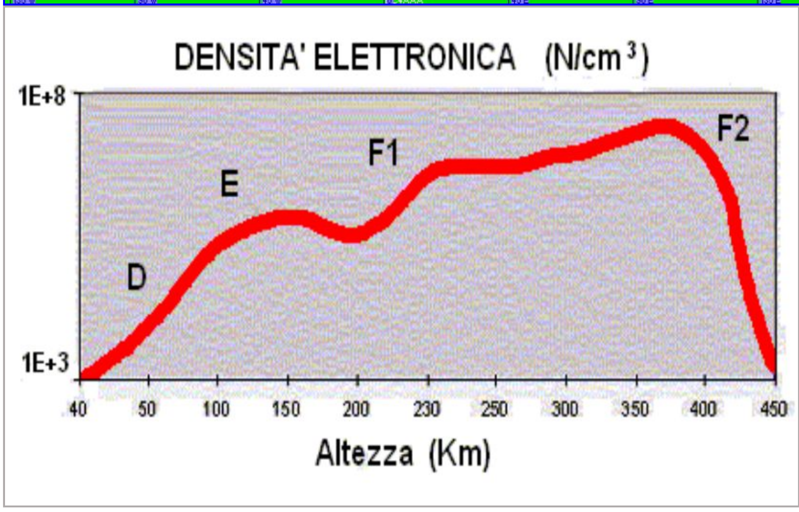
Geographical location

The appearance of sporadic E propagation depends not only on the time and season but also on the geographical location. Five distinct geographical areas are identified, based on seasonal and hourly characteristics. These areas are depicted in the rectangular map in the next page and have distinctive characteristics and propagation conditions.

In the temperate zone north of the equator, sporadic E clouds may appear at any time, but long-term observations and statistics indicate that the phenomenon occurs more often in the summer months, from mid-May to mid-August, followed by a winter period (in any case less frequently than in the summer months) that runs from mid-December to mid-January. The incidence is greatest in the morning hours 0900 -1200 and in the late afternoon - evening, 1900 - 2300, regardless of the season. There are also significant variations within the north temperate zone, with so-called local characteristics. From observations in my QTH, the openings are more frequent and intense (as signal level) in the north-west (UK) and eastward, north-east (Eastern Europe, Romania) paths. Especially for the band of 50 MHz, while they are less selective if frequency decreases, towards the HF bands. Sporadic E ionization most often occurs on the Western Pacific, China and Southeast Asia, while the presence of Es phenomena is minimal above the North Atlantic and in the east coast of North America, while in the United States the area where Es is most frequent is in the south-west part of the country. Even in the temperate belt located at south of the geomagnetic equator, propagation begins with the summer months of the southern hemisphere (from mid-November until mid-February, as it has crossed the equator, the season reverses). In the equatorial belt that stretches for 10° straddling the equator, the Es is a constant phenomenon within 8 hours per day, concentrated at the local noon, regardless of the season, but it is rare outside these times. It is possible that the high concentration of temporal phenomena along the tropical belt that develop a huge amount of energy, has interesting correlations with the formation of Es. As for auroral areas, Es is linked to geomagnetic disturbances and, often occurs in conjunction with auroral phenomena (auroral curtains always develop within region E), also at high latitudes, the

Es tends to form at night. The extent of clouds is normally greater than in mid-latitudes, allowing contacts with longer distances.





In summary, therefore, we can say that sporadic E propagation has different characteristics and causes according to latitude:

Map created using the DX Atlas software, www.dxatlas.com.

- ***sporadic E equatorial*** *occurs during the day, without seasonal preferences and is caused by turbulence induced by atmospheric tides, gravitational waves, and equatorial electrojet.*
- ***sporadic E mid-latitudes****, rare and concentrated in the afternoon-evening of the summer months, and which should be caused by the movement of ionospheric winds.*
- ***Sporadic E polar region*** *concentrated at night (late evening-early morning) without seasonal*

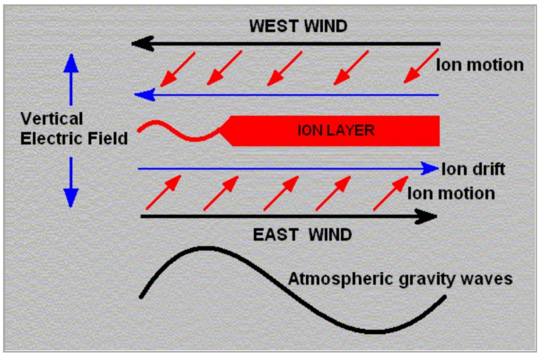
preferences and caused by the combined action of the Earth's magnetic field with auroral activity. At high latitudes, Sporadic E events with peaks of extremely high electronic densities are caused by the precipitation of particles, in fact, can be electronically conveyed to the poles by the force lines of the Earth's magnetic field and coming from the magnetosphere.

Sporadic E- Clouds structure

There is no certainty about the formation of these high ionization curtains, however one of the most accredited theories for Es in our latitudes concerns the theory of ionospheric winds (wind-shear theory), although there may be influences from weather phenomena such as temporal formations or the competition of phenomena from space, such as meteoric ablation, which could supply an additional source of ionization. Moreover, the formation of these strong ionospheric winds has thermodynamic causes (and complex laws of heat exchange between the Earth's surface and the atmosphere. The greater intensity of these winds takes place towards the end of spring and the summer months therefore at the peaks of the openings for Es, it is also possible that some phenomena that occur in the troposphere, such as thunderstorms, can also affect phenomena that occur higher up, at the height of region E.

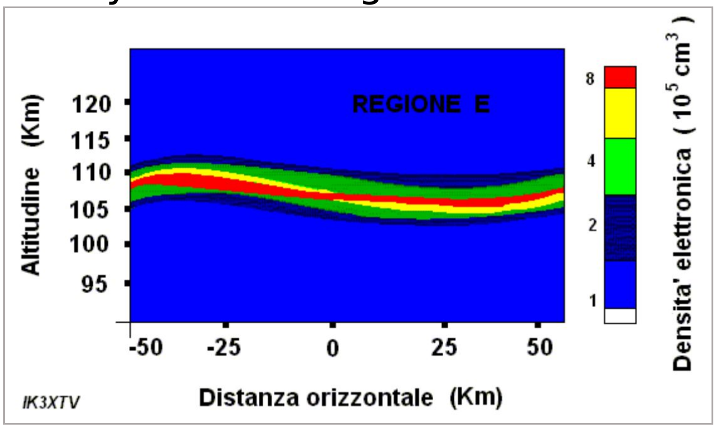
These intense winds of opposite direction, move within the ionosphere and are separated by a few kilometers of altitude, their action, combined with the action of gravity waves of tropospheric origin and the Earth's magnetic field, pushes the gaseous ions within this area accumulating them in layers that form the ionized clouds (as reported in the Figure above). This would be a vertical compression of ions that is concentrated, forming thin agglomerates with a high N, electronic concentration, with a thickness of 2 - 4 kilometers and a height between 90 and 110 kilometers above sea level. As a rule, the extent of these ionized patches is not wide, it can be 50 to 100 kilometers in diameter (at temperate latitudes), their development on the surface is a few thousand square kilometers, the concentration of electrons per cm3 is much higher than in the ordinary E layer. These are clouds of irregular shape (not circular or ellipsoidal) and not always aligned parallel to the Earth's surface, it is possible that the shape of the clouds is also concave (dome structure), measurements made with ionospheric rockets have found inclinations even up to 30°, respect to the Earth's horizon.

The limited extent of the ionized surfaces results in very selective behavior on the areas useful for the connections and create real shadow zones where the connection becomes impossible. However, this anomaly, could be explained by the dome shape of the clouds that prevents the 360° connection, as would be the case with clouds aligned horizontally with respect to the Earth's surface. The phenomenon is accentuated as the frequency of work increases, sometimes on 50 MHz and even more so on 144 MHz, connections are possible only on certain and limited geographical areas (within a few hundred kilometers). It is not uncommon though, especially in the best periods, the simultaneous formation of several areas of Es, which allow connections in several directions. I have personally observed, especially on the 6 meter bands, simultaneous openings in several directions, for example to the East (i.e. countries such as Romania, Ukraine, etc.) and westwards - Northwest (United Kingdom, France, etc.), these are, in my opinion, intense ionizations of the region and capable of reflected signals up to 50 MHz It is rare to have hyper dense Es openings in multiple directions for the 2 meter band.



Ionospheric winds and gravity waves

Atmospheric gravity waves (not to be confused with gravitational waves related to Einstein's theory of relativity), should contribute to the formation of Es curtains, acting in correlation with ionospheric winds, contributing to the accumulation of ions until ionized clouds form. Gravity waves are neutral high wavelength pressure waves (with a period T ranging from 10 to 180 minutes) that extend within the thermosphere and the mechanism that generates the wave is an oscillation caused by the displacement of an air cell that is relocated to its initial position due to gravity and the movements that generate. They are varied in nature, in the low atmosphere they are activated by different meteorological phenomena such as temporal formations, action of winds on the Earth's surface, cyclonic formations and instability caused by jet stream, while at high latitudes AGW are located more in the upper atmosphere and have causes associated with joule heating, Lorentz forces, and particle precipitation related to the magnetic field and coming from the sun. The different level of insolation between the two hemispheres results in a strong thermal imbalance that generates a wide circulation of currents in the lower ionosphere. In the summer hemisphere, more worm, an ascensional current is created, compensated by a current in the opposite direction in the cold hemisphere. This is the dynamic that generates the strong ionospheric winds.



These oscillations at temperate latitudes occur in the low atmosphere (limits of the troposphere) and consequently propagate within the Mesopause (about 90 kilometers above sea level), up to the thermosphere, fully involving E region. The state of agitation, for example, of the peak of a temporal formation is strong and this agitation can transmit gravitational waves to the Mesosphere, within which there are rushing winds, even of 300 km/h.

Fading and clouds movements

Sporadic E is characterized by a deep and rapid fading, here too, the phenomenon tends to intensify as the frequency used increases being the ionization index directly proportional to the MUF. Evanescence is due to the continuous variation of the refractive index caused by the movements of ionized clouds, which are not stable but move within E region, following the movements of strong winds and ionospheric currents. Clouds often move in the same way as weather disturbances at a rate of 300-400 km/h with shifts that can be random, although practical-statistical observation reveals a direction of displacement that at medium latitudes of the Northern Hemisphere, tends to go from southeast to northwest.

Level of ionization

The ordinary E layer of the ionosphere is between 90 and 160 kilometers above sea level, and the electron density depends on solar activity and the zenith angle of the sun, then local standard time. During daylight hours the level of electronic density and therefore ionization can be estimated at about 10 5 free electrons per cm 3, after sunset the electronic density gradually decreases because of electronic recombination up to values around 10 3 and/cm3. The Es layer can reach an electronic density level even more than twice that of ordinary day E. Depending on the ionization density of the clouds of E sporadic, depends on the frequency that is reflected to the ground, the right on the 144 MHz occurs in 1% of cases where the Es useful for HF frequencies is ascertained. To raise the MUF beyond 50 MHz, hyperdense agglomerates with a very high electronic concentration N and able to avoid shaved rays up to 200 MHz are needed, this happens less markedly than for example at 50 MHz, where in the summer months, the openings are daily.

Sources of ionization

The theory based on the east-west direction winds within layer E that move vertically because of gravitational waves and that in the presence of the Earth's magnetic field compress the ions into thin high ionization amassments, it seems particularly applicable to metal ions, such as Magnesium ions (Mg^+) and Iron ions (Fe^+) since their recombination capacity is slower than other ions and this allows massing in dense and thin layers. Ions are atoms or groups of atoms with an electric charge from neutral atoms or groups of atoms that have lost or purchased one or more electrons (recombination process). Recent measurements have revealed that Es curtains have a high content of metal ions (Fe^+ and Mg^+) as well as $O2^+$ and NO^+, the main and dominant ions present within region E. Metal ions are the remnant left by meteoric dust entering the Earth's atmosphere captured by the earth's gravitational force. It is estimated that a few tens of micro meteorites with a diameter of one tenth of a millimeter enter the atmosphere daily at a speed of the order of 100,000 km/hour, not to mention the larger particles, and the ablation takes place at the height of layer E, where the chances of collision with the gas molecules are greater (due to the high density'), also there seems to be a significant increase in the period June-August (at the densest peaks of ES). Meteoric ionization is not the only cause but should have a catalytic function in the entire mechanism, especially for the more intense Es phenomena (the one affecting the higher frequencies 50 and above all 144 MHz).

The intensity of the Es event depends on the residual ionization of the layer, the number of heavy ions present (related to meteoric precipitation) and the strength of the ionospheric winds, especially the amplitude of the wind speed change index with height, responsible for ionized formation.

Sporadic E and solar activity

The relationship between the formation of the Es layer and solar activity is not yet entirely clear.
A long-term analysis of the ratio of the K index to the geomagnetic activity conducted at 50 MHz revealed a greater incidence in the formation of Es when geomagnetic activity was low, in the presence of high K values and therefore in the presence of geomagnetic storms, the propagation deteriorated rapidly. A situation of quiet geomagnetic situation is always synonymous of good propagation and this seems to can apply also to propagation for Es. In fact, a situation of calm corresponds to a uniformity of stratifications within the ionosphere, which on the one hand reduces absorption and on the other allows a greater probability' in the formation of the Es curtains, also in the presence of an agitated magnetic field, the actual height of a layer undergoes continuous fluctuations in height , the electron density per cm3 decreases as a result of dispersion and turbulence, deteriorating those favorable conditions for the formation of reflective clouds. The connection of Es clouds with the sunspot cycle is less clear, although statistical observations in the long-range time, suggest that openings are more frequent in the low periods of the one-decade cycle (small number of spots). In periods of high solar activity, the solar flux increases by improving the level of ionization of F layer and normal E layer, however this does not seem to have a direct impact on propagation for sporadic E.

F.A.I. Field Aligned Irregularity

At the height of E region, where sporadic E curtains are normally located, super dense ionized masses of Es can form which due to ionospheric winds concentrate and converge along the power lines of the Earth's geomagnetic field, these masses then develop vertically and are tilted according to the inclination of the force lines of the field that varies from 50 to 78 degrees from the south to the north of Europe. The characteristic feature of this propagation is that to make the bilateral QSO, the signals of both stations must be sent to the diffusion zone, where the ionization is localized. There seem to be preferential geographical areas where hyper-dense curtains are concentrated more frequently and regularly (in Europe, for example, there are areas of reflection at the height of western Switzerland, and above Hungary) and this I suppose, is due to anomalies in the geomagnetic field, as well as characteristics related to magnetism within the Earth's crust of certain areas that could favor the phenomenon. The signals are characterized by a marked scintillation, similar, although of less intensity, to the scintillation introduced by the reflections on the auroral curtains, moreover the "openings" are of limited duration (tens of minutes), since the conditions supporting the anomaly seem to decay quickly. The formation of vertical masses is related to ES formations, although their bonds and interactions are not yet known. So, like propagation for Es, the best times range for this kind of propagation is from May to September and late afternoon, evening.

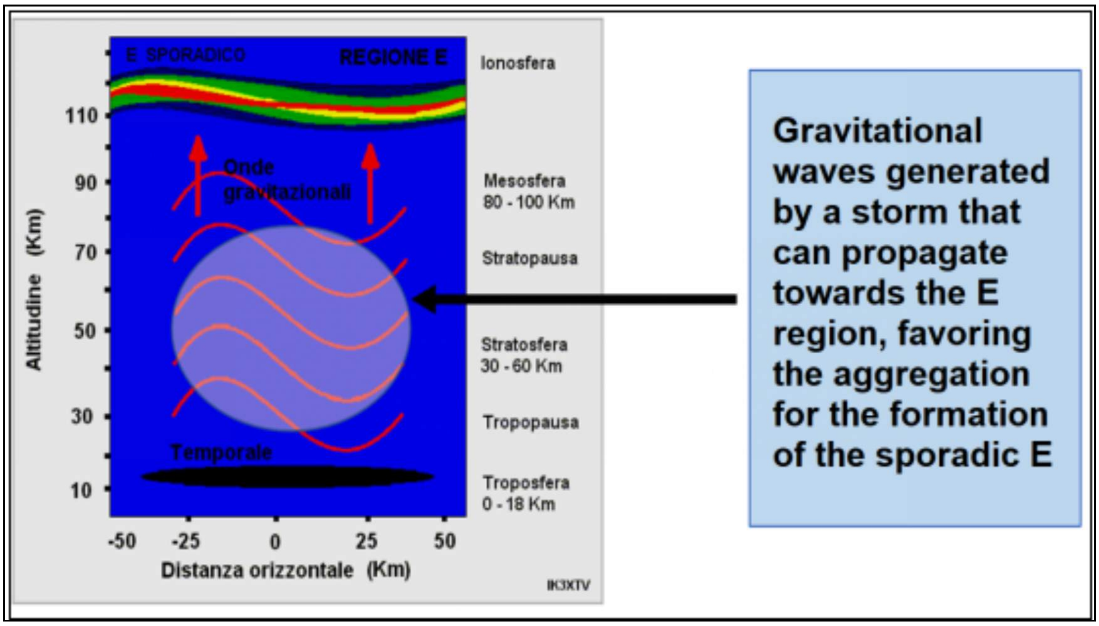
Gravitational influence of the Moon

The gravitational attraction of the moon has a considerable influence on the earth, the most noticeable effect is that of the movements of the ocean masses that generate the tides. The lunar gravitational attraction is stronger at the solstices and depends on the angular distance between the sun and the moon. The weakest tides always occur at the first and last quarter of the moon.
The magnetic field has fluctuations that follow the respective position of the moon and the sun in relation to the earth. The attraction force exerted by our satellite may also have some influence on the formation of Es. This has also appeared from specific studies conducted at the laboratories of Arecibo, Puerto Rico. Correlations have been found between the lunar tides and the development of ionospheric winds, as well as interactions with the geomagnetic field. Moreover, air molecules undergo the effect of gravity and magnetic field, gas molecules, are less closely related than water molecules and make large displacements due to solar and lunar gravitation.

Meteorological effects

The latest scientific research proves an interaction between the Ionosphere and the lower atmosphere. The aeronomy and dynamics of the absorbent D layer, the abnormal absorptions of radio waves in the ionosphere, the formation and structure of the Es, the ionospheric currents, as well as the structure of F region, should be studied in correlation with the thermodynamic situation of the lower ionospheric layers and therefore also in relation to what happens in the troposphere. This is due to the propagation from the troposphere and stratosphere to the ionosphere of a wide spectrum of atmospheric, acoustic and gravitational internal waves as well as possible gravitational influences of the moon (tides). Wind movement and circulation, turbulence and currents not only occur within the troposphere but occur up to the height of E region (up to 100-110 kilometers in height). The interaction force depends on the characteristics of atmospheric circulation, the intensity and origin of the waves. The theory of the influence of ionospheric winds, gravitational waves associated with the action of weather conditions in the troposphere should therefore have a considerable influence on the formation of Es clouds, which often seem associated with low pressure fronts. The best condition seems to be when an area of low pressure is situated between two cold fronts, since these weather conditions should be associated with strong winds and turbulence at the height of region E, these would be precisely those ionospheric winds that then create the conditions to thicken the ions creating the high-density curtains of free electrons, precisely the cause of refractories for sporadic E. The more or less intense action of gravitational waves, combined with the presence of other external catalysts such as meteoric ablation and the favorable action of the geomagnetic field, would then determine the intensity of ionization and therefore the ability to send high frequency

waves back to the ground, we know that as the frequency used increases, the Es refractive capacity becomes increasingly rare as the necessary level of ionization becomes increasingly critical, this may be due to the difficulty of having all the factors we have just talked about at the same time active. There should also be a correlation between thunderstorms and the formation of the sporadic E layer. Practical observations would seem to confirm this theory. Many radio amateur operators, on the 10 meter band, for example, frequently experienced a significant improvement in propagation conditions immediately after a temporal phenomenon. The correlations between the lower and higher layers of the Earth's atmosphere would seem to support this hypothesis.



The violent agitations within a temporal front generate gravitational waves that transmit to the ionosphere and this could be linked to the improvement of the propagation conditions triggered by the storm as well as the possible link between thunderstorms and sporadic E. Although it has not yet obtained scientific approval, it is supported by amateur radio workers based on practical observations and statistics. However, official science would tend to exclude such a relationship by arguing that the transition zones between the troposphere and the ionosphere, called tropopause and stratopause, protect reflective layers from influences on molecular composition and electronic concentration by tropospheric phenomena, as well as not finding a statistical relationship between the occurrence of Es and thunderstorms. It is also true, however, that about 100 temporal electric discharges occur statistically on earth every second, with a concentration especially in the equator belt and summer hemisphere (the incidence of ES is higher in the summer months and in the tropical belt), recent NASA studies have found a higher frequency of lightning on dry land than in the sea and a greater concentration in the African tropical belt, in North America and Southeast Asia. These electric discharges develop an impressive amount of energy, so we have a huge level of potential energy that could function as an Es catalyst, it is certain that not all temporal cells give rise to the formation of Es, but a combination of events could take place where electricity could have the trigger function. A further link with the hypotheses just discussed concerns the discovery made in recent years of an interesting phenomenon associated with thunderstorms, these are the Red Sprites.

Practical observation

During the IARU 50 MHz contest, I monitored the development of propagation from my QTH, in JN55RQ to see the behavior of the 50 MHz, with systematic observation (about 150 stations heard in 59 different locators) from 08:30 UTC to 14:00 UTC, in June 22, 2003. An international contest is a good opportunity for propagation studies since many stations are active simultaneously over a wide geographical area. In this way, the sample of available data is certainly reliable. The propagation proved to be remarkably good, the band was opened continuously throughout the time frame, and in several directions at the same time (i.e. from the Iberian Peninsula, France, the United Kingdom, Southern Scandinavia, Eastern Europe to Romania and Bulgaria) although I noted a cyclical trend with high intensity peaks towards a certain (predominant) direction followed by moments of low propagation in all directions (even if the band was never closed).

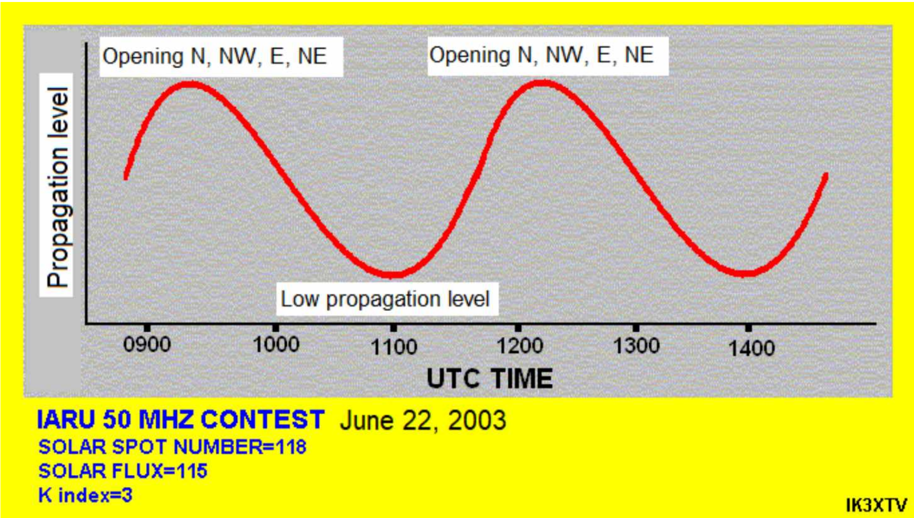
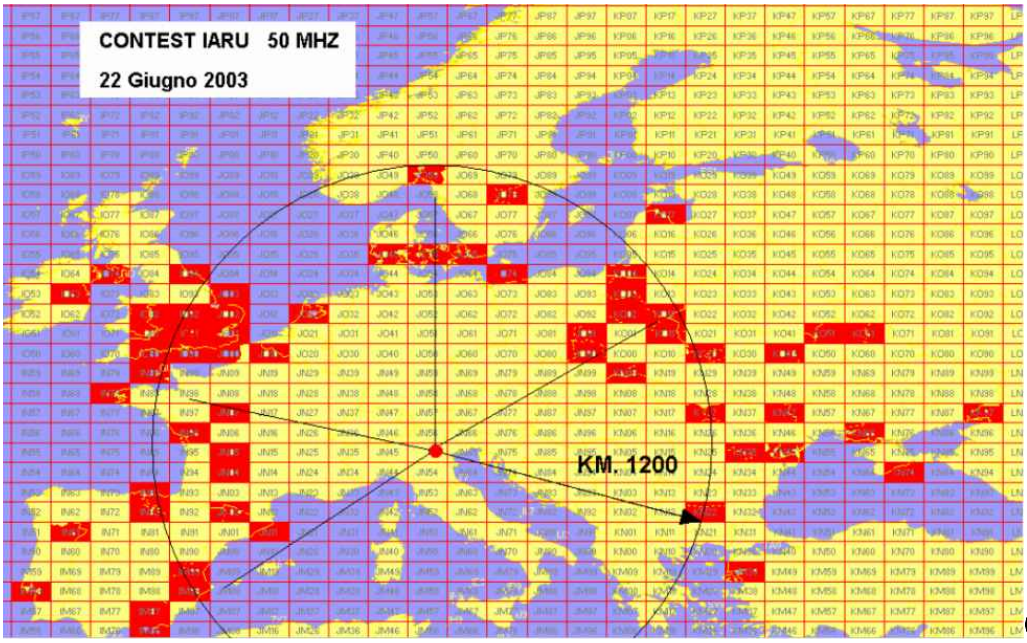
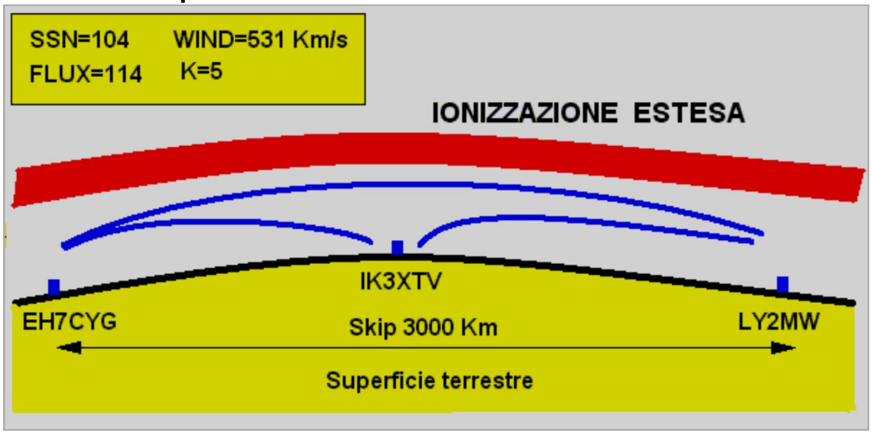


Fig. Cyclical trend of propagation.



On the south side, however, I have not listened any stations, the propagation in this direction has always been closed. The shadow zone was about 800 kilometers and a preferential skip was around 1100, 1200 kilometers. The weather situation was good, with high pressure air in Italy and Central Europe, squeezed between two low pressure fronts located one over the UK and the other over Eastern Europe. The solar indices were respectively: Number of spots 118, Solar flux 115 and index K=3.

Practical observation of the 50 MHz band suggests other considerations relating to the extent and movement of ionizations. At the best of times there seem to be extensive ionizations that raise the MUF up to frequencies of 50 MHz, as to explore further this, I would like to report some other observations during another day: June 24, 2003, always in 6 meter band.
From 17:30 UTC, the propagation was open with a preferential direction to north direction, discrete signals came from Southern Scandinavia, but. From the northeast Europe, since the signals were even stronger from the Baltic Republics, (Estonia, Latvia, Lithuania).



At 17:45 UTC, I connected LY2MW, from Vilnius – Lithuania, with a skip of 1400 Km, immediately afterwards, LY2MW also connects a Spanish station, EH7CYG, from Cordoba in Andalusia, the distance between Vilnius and Cordoba is 3000 Km, unusual as a skip for a summer connection in 50 MHz and unusual also the fact that I could listen to both stations. There were extensive and aligned ionizations along this path, from the Iberian Peninsula, through central Europe to the Baltic Sea, which made possible these contacts. It seems, in fact, especially when the conditions are better, these areas aligned (perhaps even more than one) along a certain direction, presumably linked to the direction of the lines of the Earth's geomagnetic field that are not static but move, following rules not yet known but which I think can be determined by the influence of external actions such as Earth rotation, solar radiation pressure, ionospheric currents and general weather situation, geomagnetic field. Later, around 18:35 UTC, propagation opened to the UK, but at the same time signals were also coming from Eastern Europe (Romania, Ukraine), so there was another ionized belt from Britain, across central Europe to Romania. The movements of the ionized curtains make the direction of the propagation openings very variable, as regards the altitude of the reflections, these tend to rise as the sun progresses westward, since the distance of the connections tends to lengthen progressively after sunset. However, it is not easy to understand these mechanisms, because radio propagation phenomena, due to their sporadic and unpredictable nature, always reserve surprises.

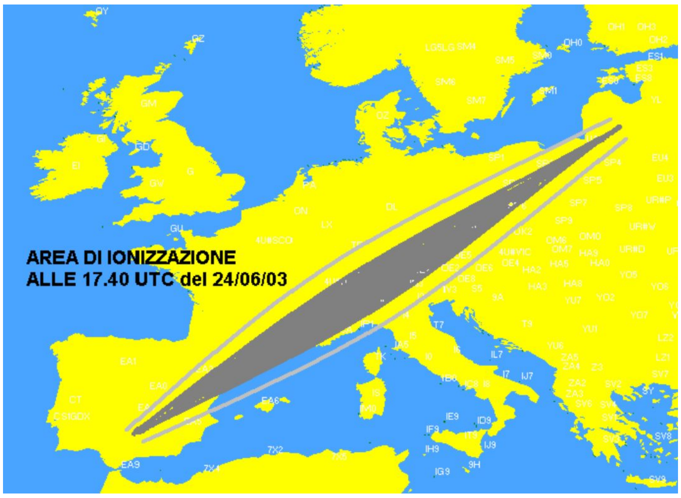


Fig. The map of Europe reconstructs the ionization present at 17:40 UTC of 24/06/03. As in this case, at other times the same ionization is formed in the opposite direction, from north-west to south-east (from the United Kingdom to the island of Crete) as observed on 26/06/03 at 16:45 UTC and the hypothesis is that they orient themselves following the movements of the geomagnetic field (data based on listening to the band of 6 meters). The QSO between EH7CYG and LY2MW allows me to introduce a concept about the propagation distance. Simple geometry considerations show that the maximum theoretical distance of a single Es jump is about 2100 km. It is not uncommon to see connections in 50 MHz and 144 MHz, over considerably longer distances and this should be due to the contribution of tropospheric propagation at the beginning and at the end of the path, which lengthens the distance. However, the distance of 3000 km seems excessive and therefore it is possible that the connection has enjoyed double jump propagation, taking advantage of the extensive ionization about which we have just talked.

Investigation of the plausible causes of Hyperdense sporadic E

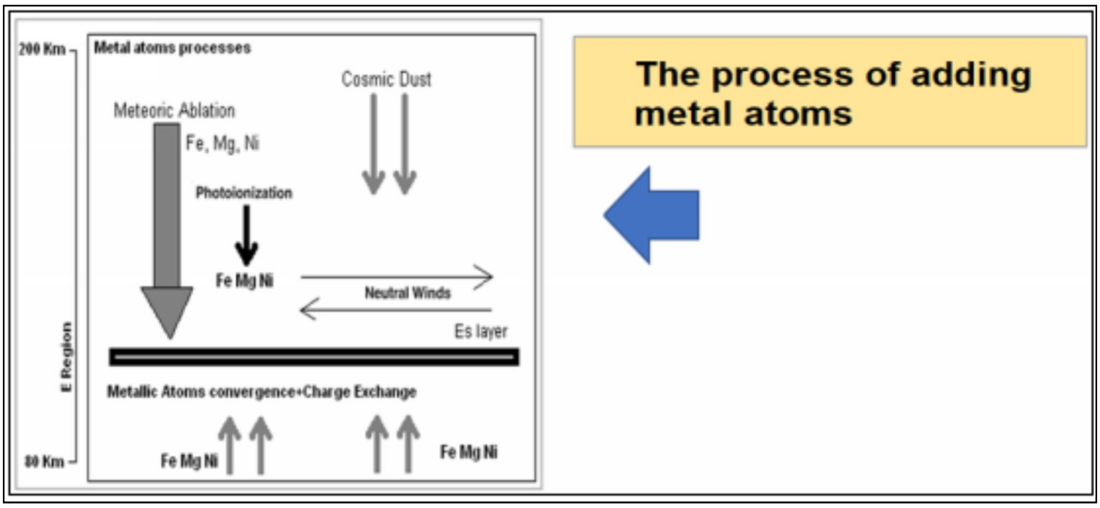
Introduction

Sporadic E openings affecting the VHF band of 144 MHz are only 5% of all Sporadic E events. Highly ionized (hyper-dense) structures capable of raising Es MUF above 100 MHz are needed. The aim of this document is to investigate the plausible causes of the formation of these structures to understand the mechanism for increasing the ionization of the stratum. The intensity of the Es event depends on the residual ionization of the layer, the number of heavy ions present (relative to the theoretical input) and the strength of the ionospheric winds, especially the amplitude of the wind speed change index with the height, responsible for the ionized massing. But what could be the mechanism of creating hyper densities layers?

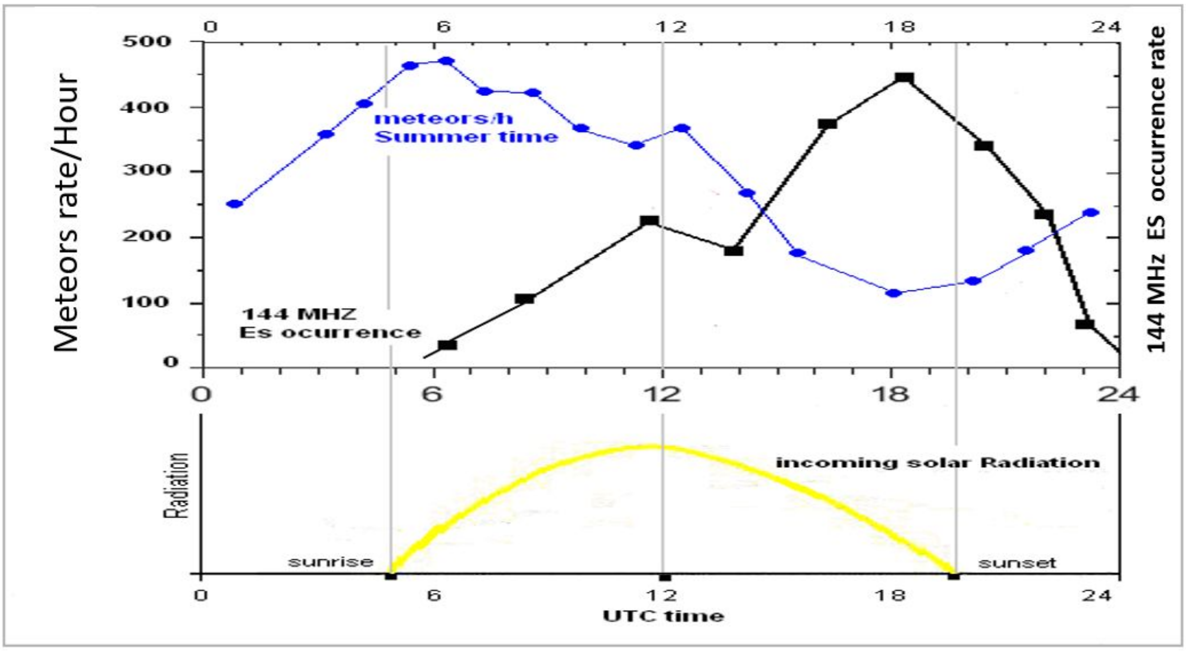
The effect of UV ionizing radiation of the sun

Atomic metal elements such as Iron, the most present metal element, has a low ionization potential and therefore lots of iron atoms can become ions by photoionization by UV radiation of the sun. The daily solar radiation curve is important in the formation of sporadic E as it contributes significantly to the life process of metal ions (see figure below). A statistical analysis of Es openings at 144 MHZ shows two peaks, one around noon and the other even more intense near sunset. The Es event curve is out of phase with the intensity of the meteor input. Thus, to have a hyperdense layer a high concentration of metal ions is needed. The ions derive from the meteoric dust and the subsequent ionization process present at altitude, a part of this ionization takes place by oxidation or divestiture of charge with molecular ions, a part takes place thanks to the photoionization process. Consider that metal ions can also have a life of a few hours, within E region. Practical experience teaches us

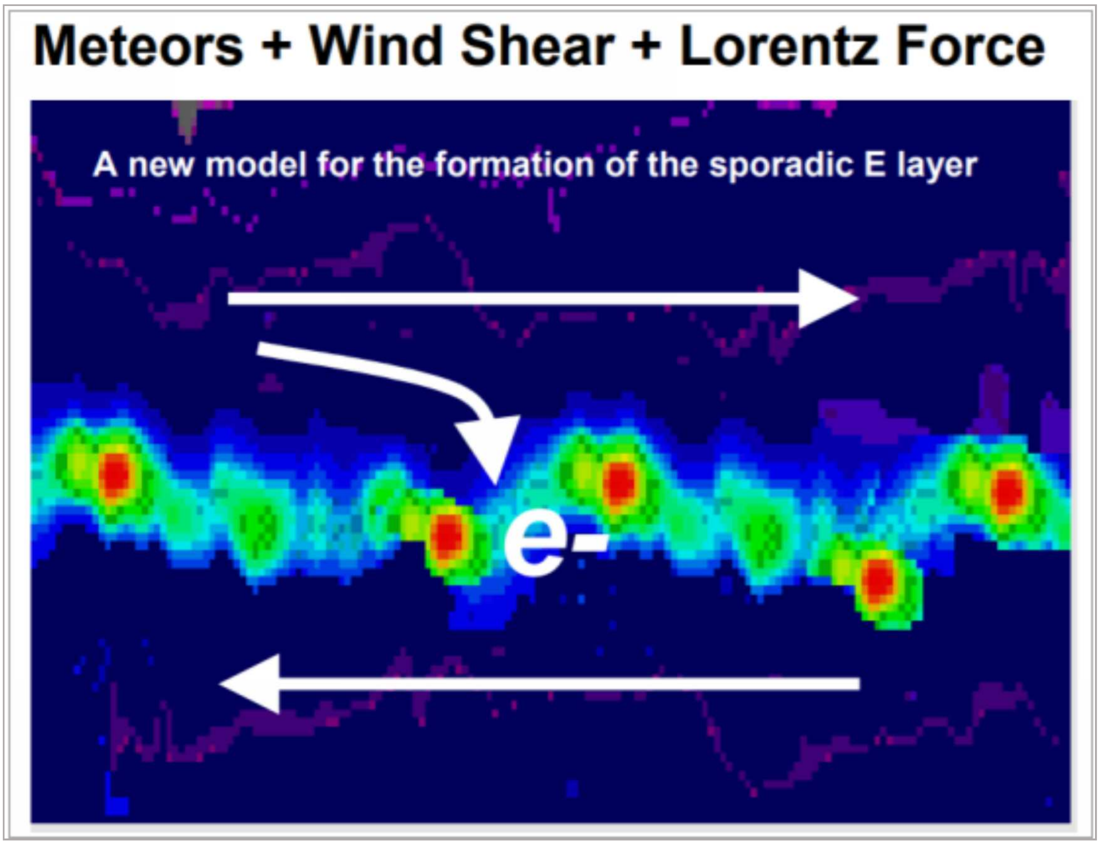
that the increase of Es MUF are not sudden, but follow an additive process, in fact the MUF rises progressively with openings that first involve 10 meters, then 6 meters and only in a few cases the ionization manages to grow to support the propagation on 2 meters. This additive process is the sum of several events: Peak theoretical input above the average of the prolonged action period of UV radiation that increases by photoionization the metal ions+ action of ionospheric inverse winds (another fundamental element without which layers cannot form.



The peak of meteoric input occurs in the early hours of the morning, while the peak of Es events occurs in the early hours of the evening. There is a mismatch between these two factors. In the middle of the day, we have the maximum level of solar radiation. What is the cause of this hysteresis? It is difficult to answer this question: We do not yet know well the role of ionospheric winds linked to atmospheric tides.



Sporadic E - A new model: Meteors + Wind Shear + Lorentz force

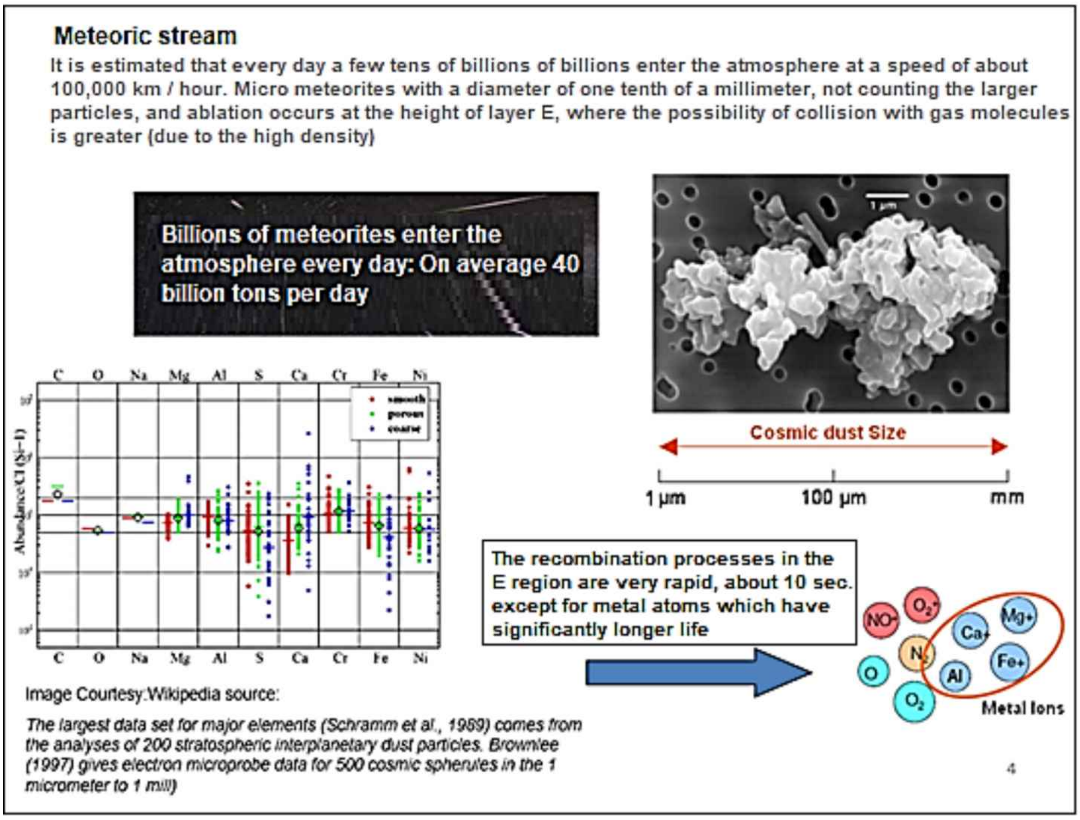


Now the most accredited theory for explaining the formation of the sporadic E layer is that of the Wind Shear. With the help of my friend Giorgio Marchi, IK1UWL, I did further studies that led me to the formulation of a new model, always linked to the Wind Shear, but which introduces the contribution of the Lorentz force and the separation between ions and electrons. This new model, I thought to call it "Meteor + Wind Shear + Lorentz's Force". Previous models and theories always spoke of an accumulation of ions. The novelty lies in the thickening mechanism of a layer of N free electrons because, as we will see below, they are responsible for ionospheric refraction.

The meteor flows

The raw material is supplied by the material that enters the atmosphere and burns by friction, given the extremely

high rate of entry, forming both directly ions (for overheating) and ionized oxides combining with oxygen ions (these formed by UV rays) present at those altitudes. (The metal atom loses an electron and becomes an ion+).

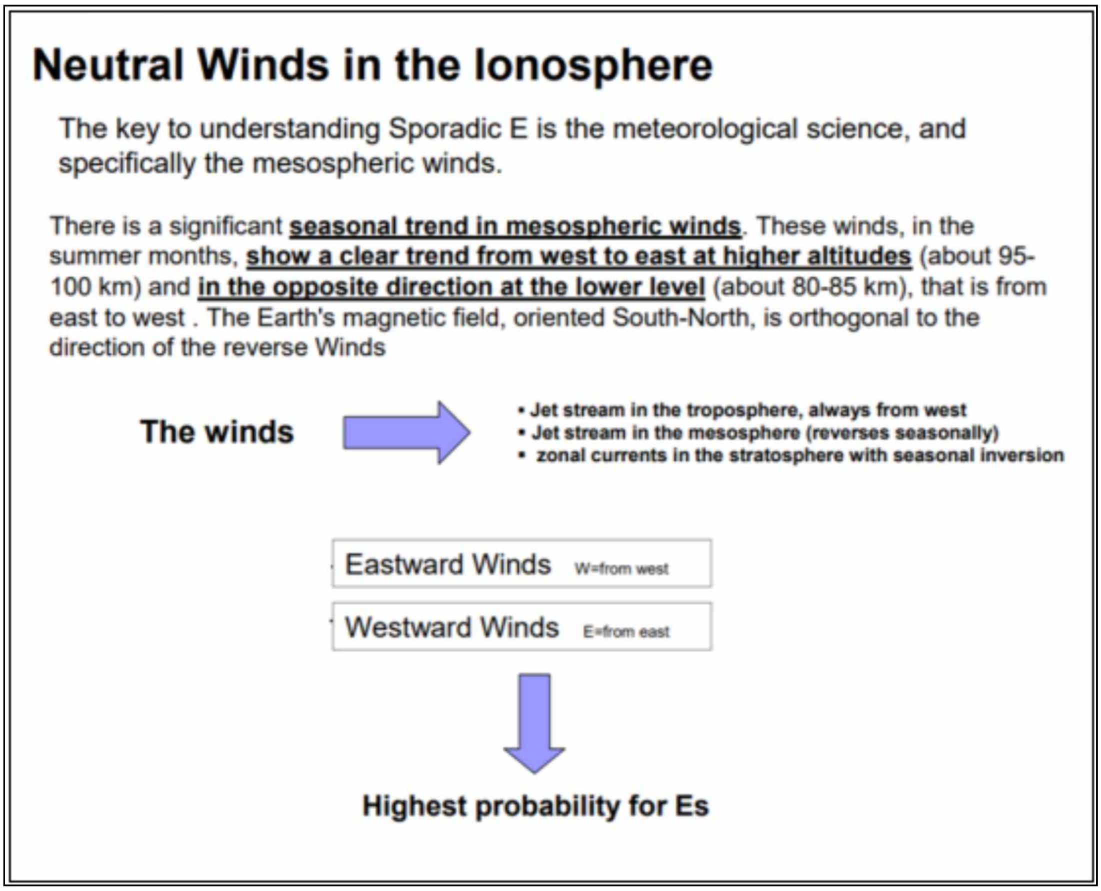


Images credits: The authors of figure of cosmic durst are Donald E. Brownlee, University of Washington, Seattle, and Elmar Jessberger, Institut für Planetologie, Münster, Germany. This file is licensed under the Creative Commons Attribution 1.0 Generic license.

Neutral zonal winds

The key to reading the sporadic E must be search in meteorology. Especially in the dynamics of neutral winds in the mesosphere. We know that the raw material is provided by the meteor dust material that enters the atmosphere that burns by friction given the very high rate of entry forming both directly ions (for overheating) and ionized oxides combining with oxygen ions (these formed by UV rays) present at those altitudes. (The metal atom loses an electron and becomes an ion+). As we have already said, what varies most in the short term is the speed of the wind. But it is also the most difficult parameter to predict and control. It has significant variations in size on a local scale. However, there is an important seasonal trend and because of a complex mechanism of large-scale atmospheric circulations (Polar Vortex VP and reverse circulation: consider that the polar vortex is the system that in practice governs weather in mid-latitudes. These winds in the summer months show a clear trend with a trend from West to East at higher altitudes (about 95-100 km) and an opposite direction at a lower altitude (about 80-85 km), i.e., from east to west. The Earth's south-north-oriented magnetic field is

orthogonal to the direction of inverse winds. Lorentz's force separates positive ions from electrons, accumulating electrons in the center, dispersing ions outwards. In the winter months there is a reversal in the circulation of prevailing winds. We said that the reflection of the electromagnetic wave is due to electrons. The favorable summer combination of wind trends, combined with the increased meteor shower, is the cause of the marked summer occurrence.



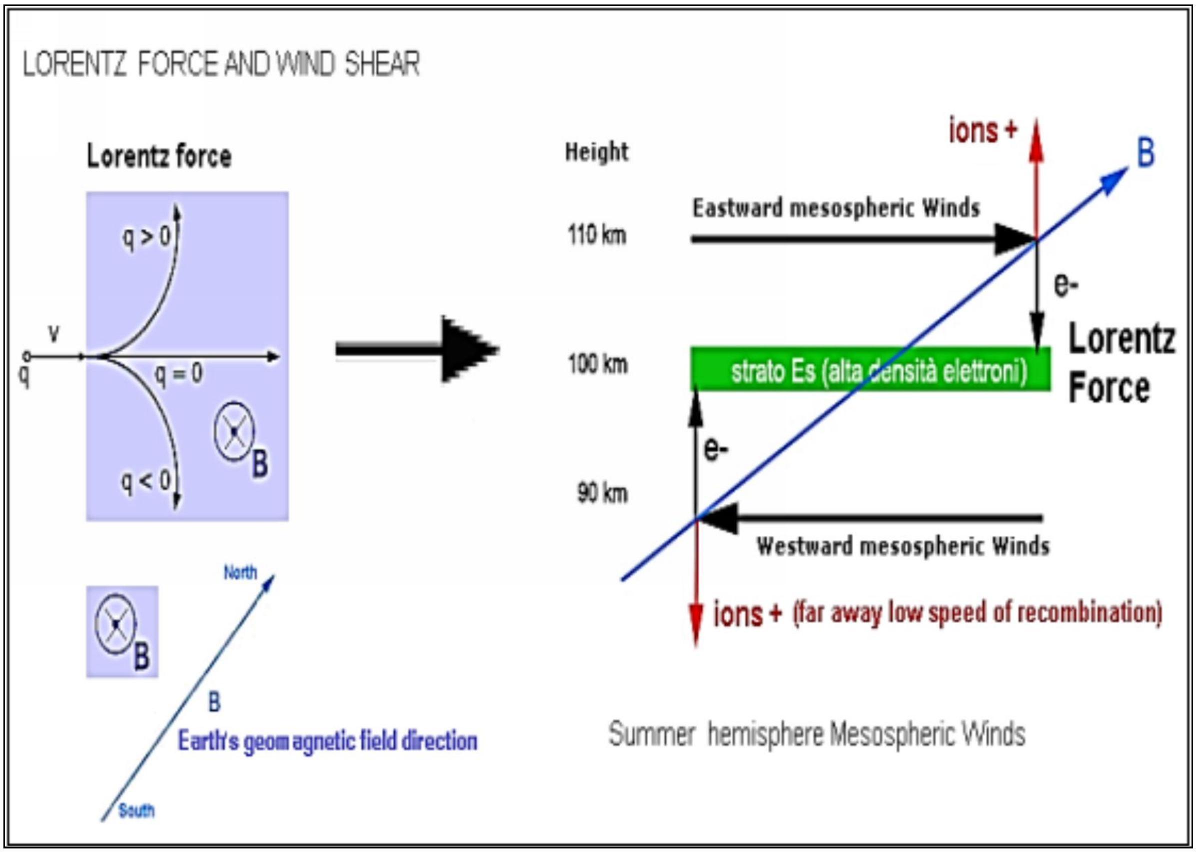
Lorentz's Force.
In physics, the Lorentz force is the force acting on an electrically charged object moving in a magnetic field. The main feature of the Lorentz force is that it is always directed perpendicular to the direction of motion (which has assumed the electrically charged object within the magnetic field). It therefore does not perform mechanical work (variation of kinetic energy), but it has an effect only on the trajectory of the charged particle or is a deflecting

force. The Lorentz force is the force exerted $\mathbf{F}$ by the electromagnetic field on the charge, and is proportional to q and to the vector product between $\mathbf{v}$ and $\mathbf{B}$, according to the equation:

F= q x V x B

Where:
F= is the force exerted by the electromagnetic field
q= electric charge
V=instantaneous speed
B=Magnetic induction field

The Lorentz force applied to the ionosphere and direction of zonal winds



The force rule acting on an electric current immersed in a magnetic field is clear and has no exceptions, if electrons-and-ions+ move in the same direction, the forces on them are of the opposite direction. When the upper wind goes in one direction (and the lower wind in the other) the ions

thicken, when it goes in the opposite direction (and vice versa for the lower one) the electrons thicken. Since electrons are responsible for the reflection of the electromagnetic wave, we have sporadic E, when we have amassing electrons, and this happens with a verse of zonal neutral winds as in figure below. In practice, the combined action of the winds + Lorentz force makes a separation between the ions and electrons and forms a dense layer of electrons. The removal of metal ions and therefore their slow recombination.

Fig. Graphic diagram of the Wind Shear+ Lorentz force model, responsible for the concentration of the electron layer in the middle. The pattern refers to the summer months where the dominant trend of the winds is to the east for the upper ones and to the west for the lower ones. Only with this direction of zonal neutral winds, the accumulation of free electrons is possible. The refraction of radio waves in the Ionosphere is due to the concentration of free electrons N. (Graphic by Giorgio Marchi, IK1UWL).

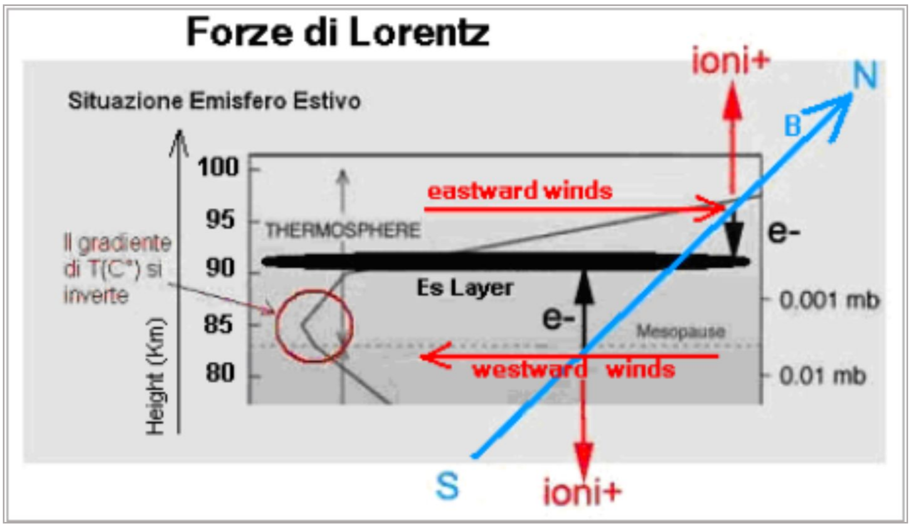
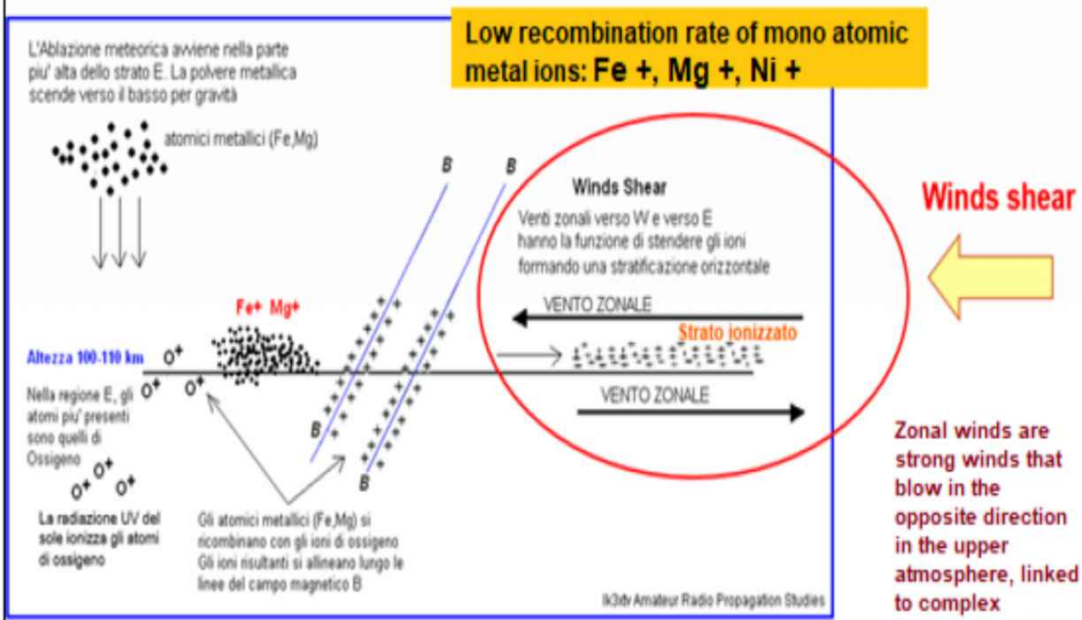


Fig. The figure shows in detail what happens at an altitude around 90 km. Lorentz force associated with the winds and force lines of earth's magnetic field B that go from south to north.

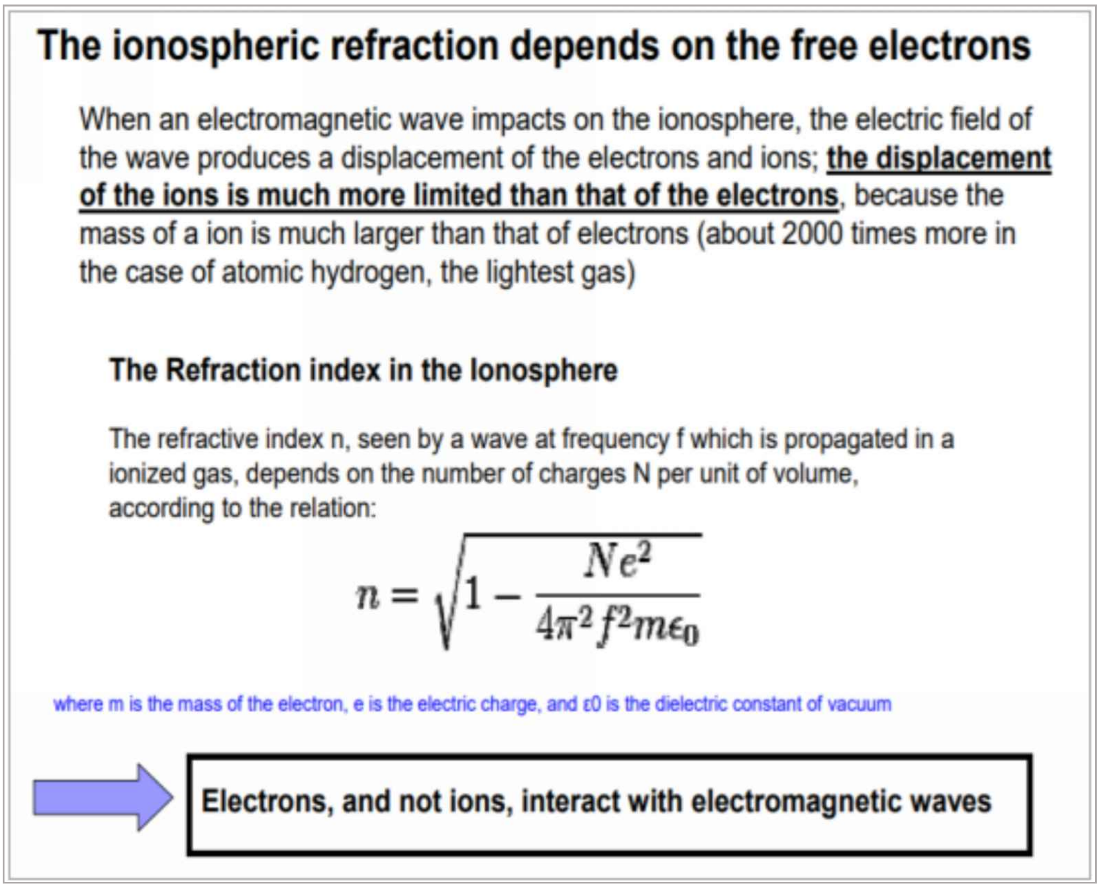
The mechanism of formation of the layer

The ion layer is created by the motion **V X B**, where V refers to the zonal neutral wind speed and B is the horizontal component of the earth's magnetic field (the lines of force of the magnetic field are orthogonal to the wind direction). When there are zonal neutral winds to the west and east directions , the ions align themselves along the lines of force of the magnetic field and are spread by the force of the wind in thin layers. In practice it is like a rolling mill.



Zonal winds are strong winds that blow in the opposite direction in the upper atmosphere, linked to complex meteorological dynamics

- The ions line up along the magnetic field lines.
- The action of the ionospheric winds stretches the ions, creating ionized layers.
- Contamination with metal ions, oxidized by O + ions of the E layer, transforms the layer into a layer with a low recombination rate and therefore denser.



Some considerations

1 - If a ion is carried by the wind it becomes in effect an electric current. If there is a magnetic field perpendicular to this current, a force is born that acts on the ion in a direction perpendicular to the plane containing the velocity vector and magnetic field vector. If this plane is horizontal, the force is vertical.

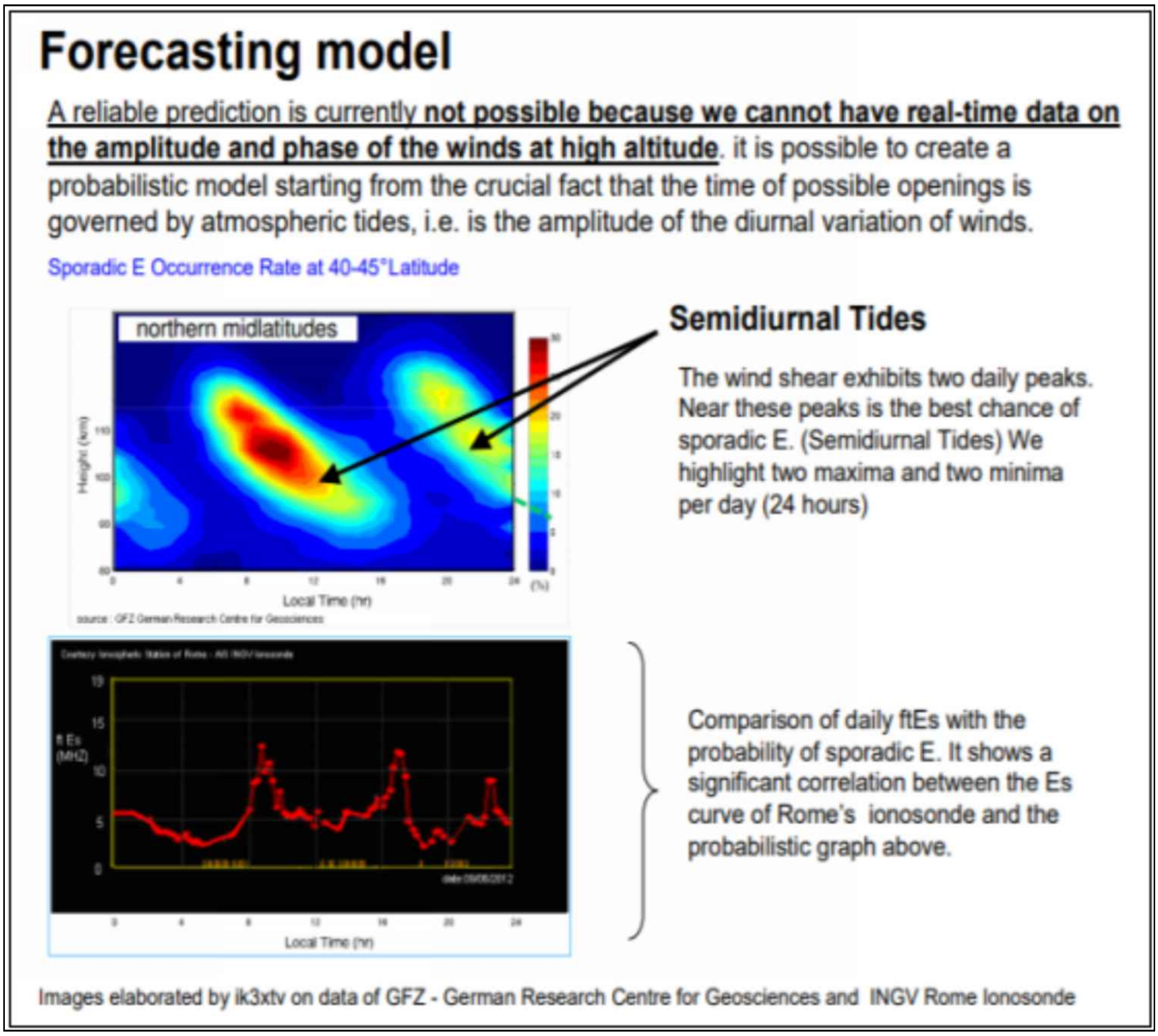
2 - Since they exist on the 80-85 km altitude winds (periodic) in one direction, and on the 95-100 km of altitude winds in the opposite direction, the electrons (negative charges) present at these altitudes are concentrated in a layer at about 90-95 km of altitude, because those in the lower current undergo an upward force, and those of the upper current, opposite as velocity but with the same direction of the magnetic field, are pushed down. Ions + (positive charges) undergo the reverse process.

3 – At these altitudes there are always ions and electrons, especially metal ones that burn at 80 km altitude, in the

summer months a minimum of Es layer is always present there. This is also confirmed by recent studies by the University of Crete, which with extremely sensitive instruments has detected the presence of Es layer that is not detected by ionosonde (less sensitive). The density of the layer is proportional to the velocity, magnetic field and ion density, because the phenomenon varies so much from day to day? The extent of the wind is linked to seasonal phenomena, not daily phenomena. The magnetic field, on the other hand, it is influenced by solar events. And the number of meteorites varies over time. Explanations. Of the three variables: Wind speed, magnetic field, presence of ions. what varies most in the brief time is the wind speed.

A few comments:

1 -When the wind Shear has a certain verse you have concentration in the middle. When the Wind Shear has the opposite direction, you have thinning instead of concentration, because you reverse the forces. This is consistent with the time duration of E layer observed.



2 - The wind drags both positive ions and electrons in the same direction. But the strength due to the magnetic field acting on positive ions is in the opposite direction to that which acts on electrons. So overall the electrical equilibrium is there, but not locally. In the sense that the dense Es layer is formed only by electrons, while the Ions + are moved above and below. This is also the most logical explanation for the high recombination times. In normal ionospheric layers for example (the highest layers), which are formed because of UV radiation, there is no separation between ions and electrons, and in fact, given the proximity, a continuous recombination process takes place, slowed only by the intense process of solar ionization. When the sunset, recombination is rapid, regardless of what ions they are. Even if they had been metallic, the recombination would have been rapid the same, the pull

force between an electron and an ion + is independent of the nature of the ion, it depends only on the square of the distance.

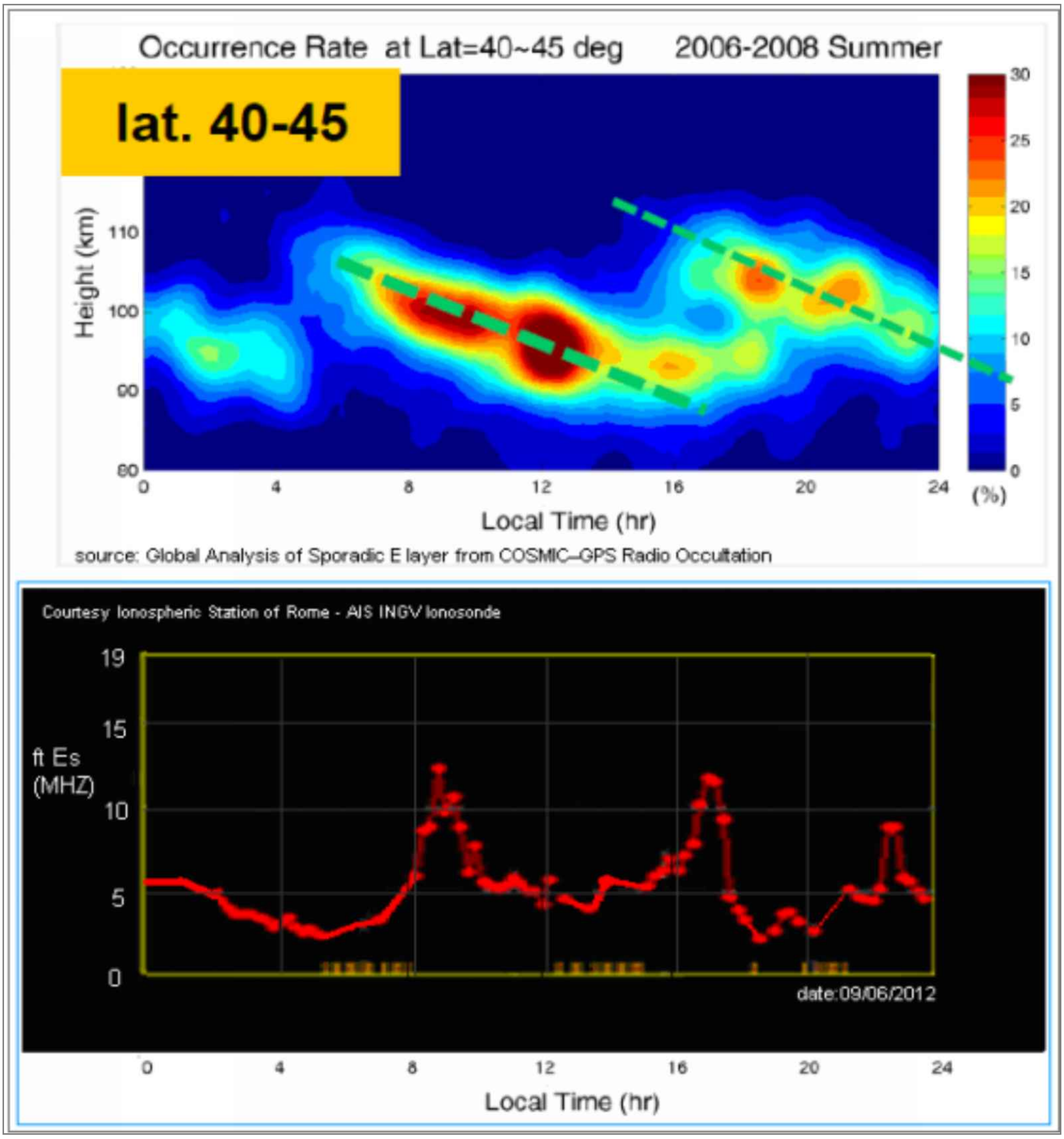


Fig. Comparison of the daily trend of the ftEs with the probability of sporadic E. A significant correspondence emerges between the Es curve at Rome and the probabilistic graph at the top (Elaboration of the GFZ German Research Centre for Geosciences).
It should also be noted that the height localization of the openings tends to descend (Dotted line). Top image: processing ik3xtv on CHAMP, GRACE and FORMOSAT-3/COSMIC data.

Source: Global Analysis of Sporadic E layer from COSMIC–GPS Radio Occultation.

In the next page, there are tables that show the probability of Es based on local time. The charts are divided by latitude.

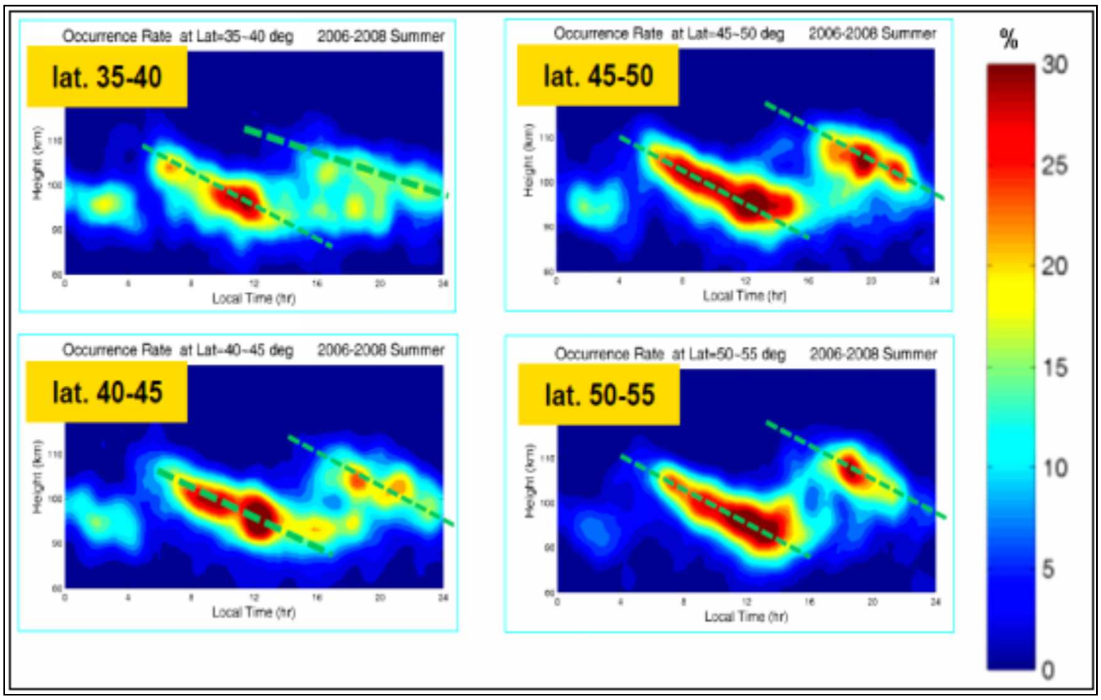
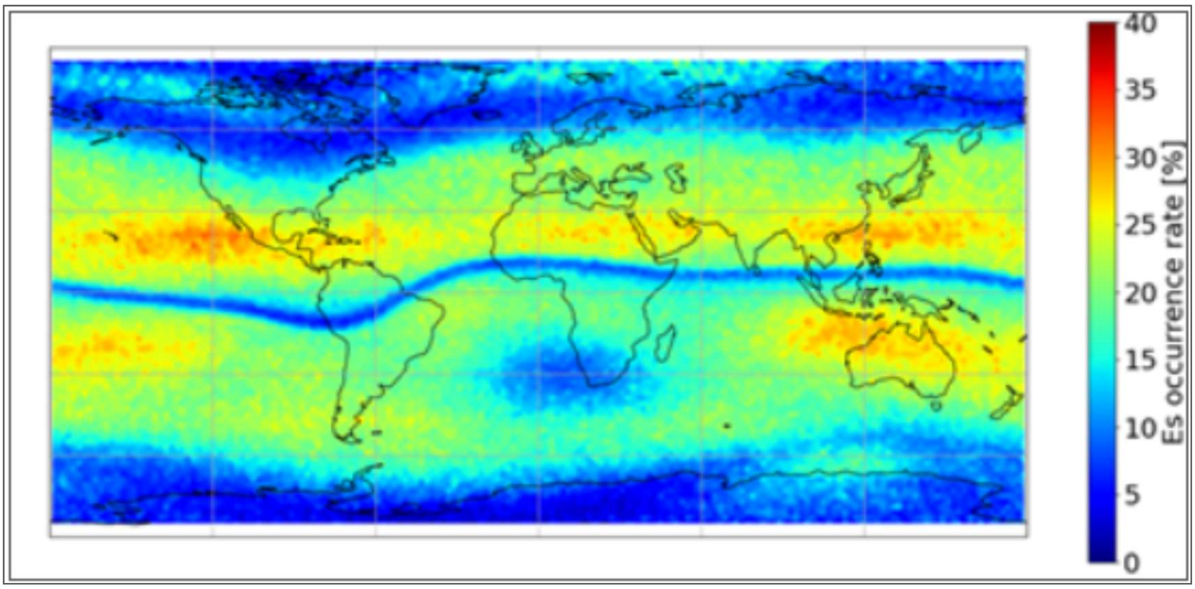
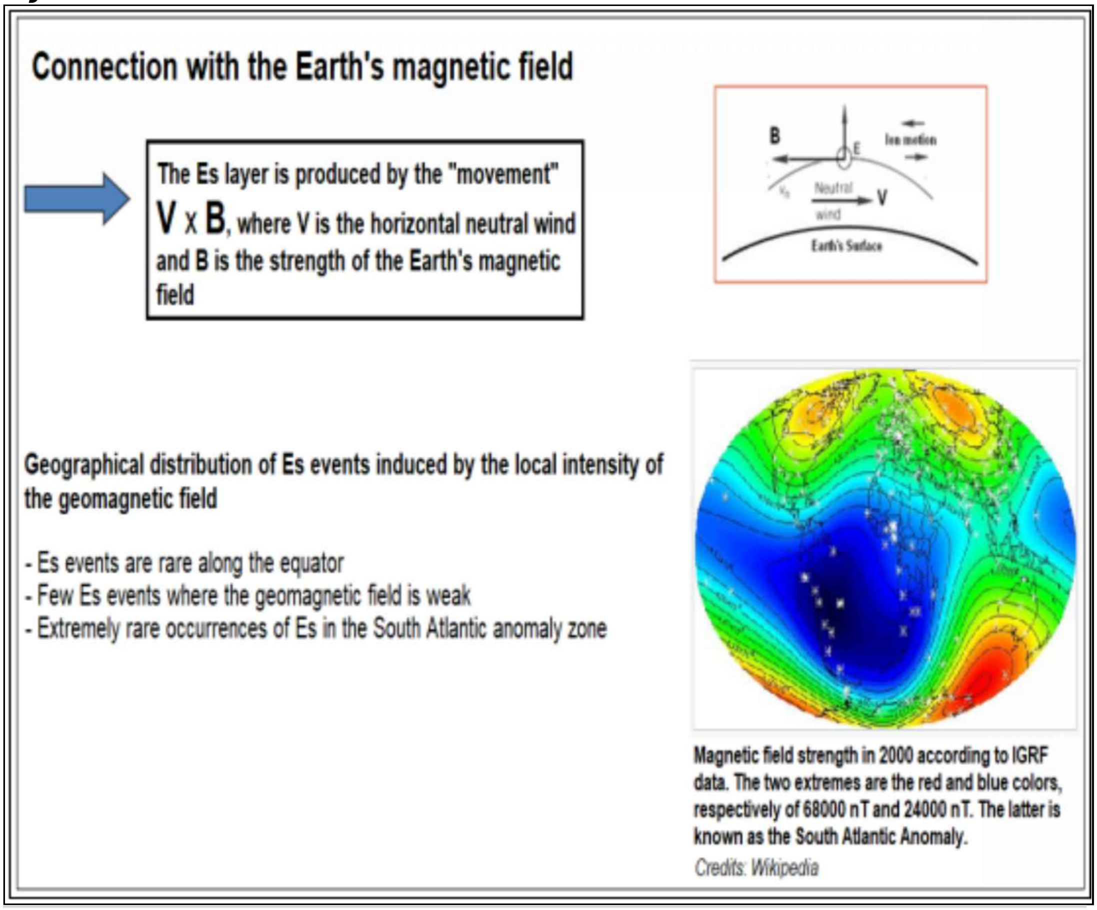


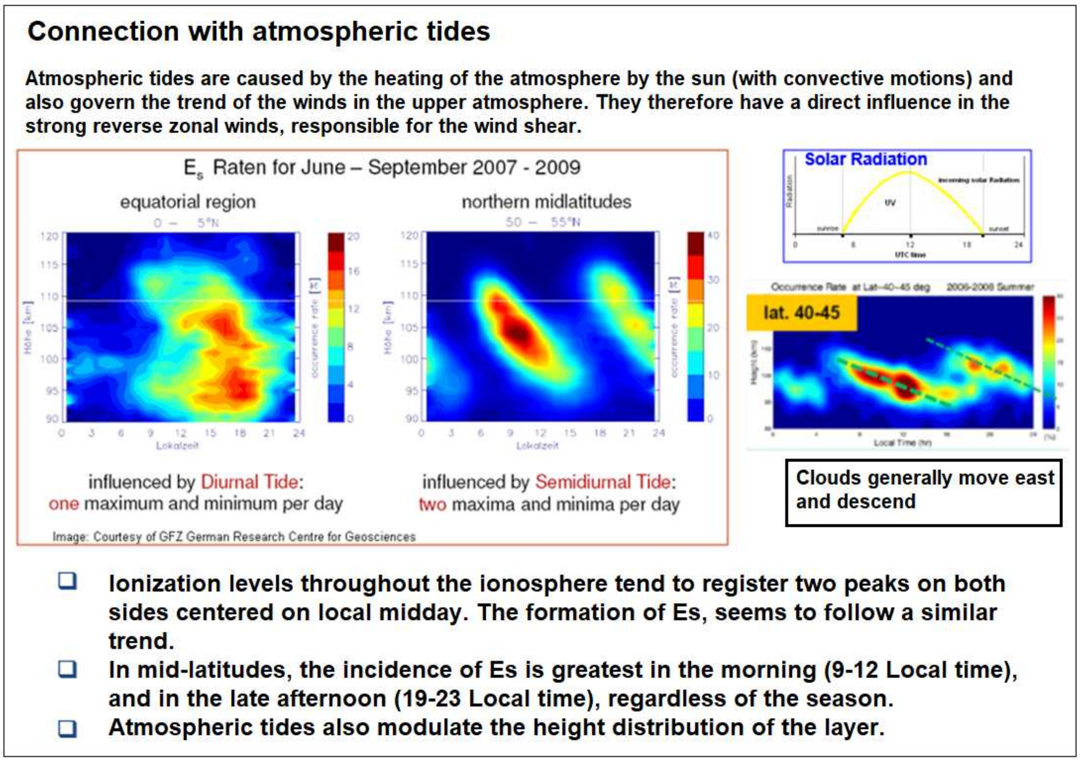
Image: Dr. Christina Arras - GFZ Potsdam Section: Space Geodetic Techniques.
Global Analysis of Sporadic layer from COSMIC–GPS Radio Occultation



from Measurements of CHAMP, GRACE and FORMOSAT-3/COSMIC.

Fig. The global sporadic E distribution looks like when they merge several years of data, dated 2022. Image provided by Christina Arras of the GFZ Potsdam





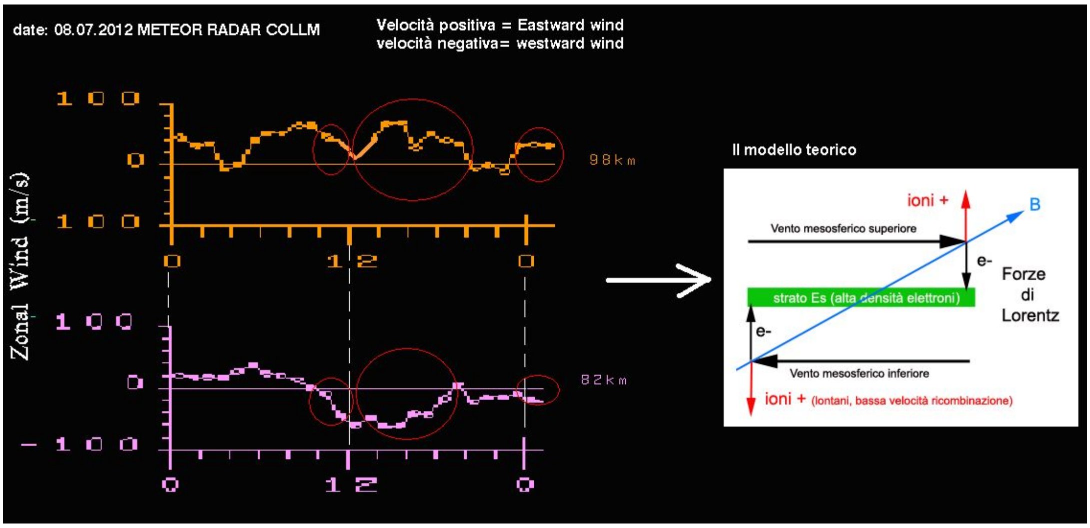


Fig. Practical analysis using Collm's Radar meteor in Germany that records the velocities of zonal winds at high altitudes. The altitude shown to the right of the wind speed diagram. I extrapolated the wind trend above 98 km (marked eastward trend) With amplitude influenced by the semidiurnal tides. The wind below 82 km has a prevailing trend towards the West, especially for daylight hours. With marked breadth in the middle of the day. I circled the Wind Shear phases and electron accumulation. Then formation of Es.
Speed scale: 100 m/Sec=360 Km/h (Image processed by Ik3xtv from Collm Radar meteor data).

Variations in meteor flux
The meteor flux is not constant but has variations:
- Seasonal variation (average flux about six times higher in the summer months)
- Daytime variation (peak in the morning followed by progressive decrease)
- Hourly variation

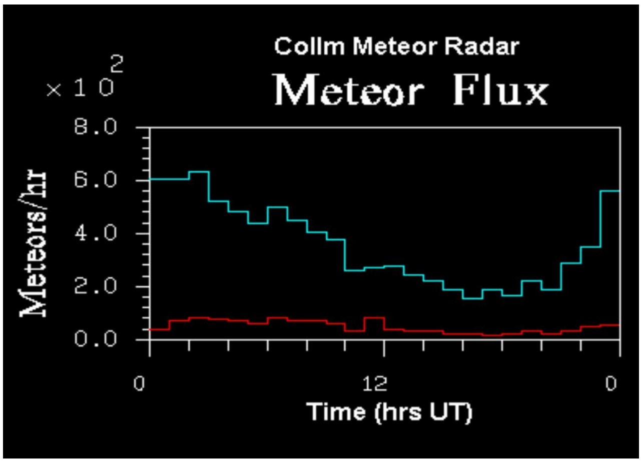
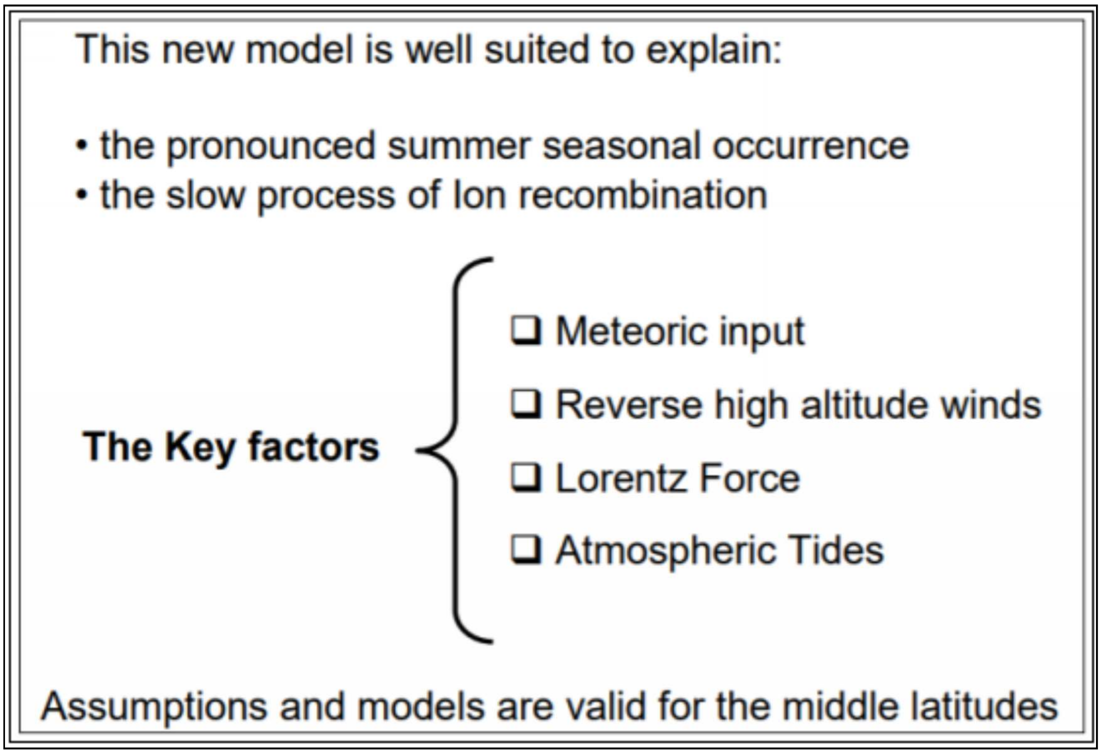


Fig. An example of the daily meteor shower curve of the Collm-Germany Meteor Radar. Peak flux occurs in the early hours of the morning followed by a gradual decrease throughout the day. Note the hourly difference between the arrival of the largest amount of mass and the maximum hours of Es (see probability tables) due to migration by Lorentz force.
Courtesy: SAO/NASA Astrophysics Data System (ADS) (Ceplecha, Z. & Padevěv, T. Astronomical Institute of Czechoslovakia).

Conclusion
This new model lends itself well to explaining the marked summer seasonal occurrence of the Es phenomenon and the slow process of recombination of the ions. It also

shows that sporadic E events need very precise vectors of inverse winds (upper eastward wind and lower westward wind). If these vectors change, electronic thinning takes place and therefore you cannot have sporadic E. In the summer hemisphere, the prevailing direction of mesospheric winds is favorable to the accumulation of free electrons, vice versa in the winter months the direction of the winds reverses. The difficulty now is to predict the amplitude and vector of the winds and this is a big limit for the forecast.
Note: Assumptions and models are valid for mid-latitudes.

Some considerations
The Lorentz force deflects the trajectory of the electron until it moves horizontally; when the Lorentz force moves vertically, it ceases to act, and the electron continues by inertia with the speed reached. The fewer ions it finds in its path, the more likely it is to go as far as the wind is reverse, and Lorentz’s strength again acts by slowing it down. Since the central altitude at which the meteor dust is vaporized is about 90 km, and coincides with the wind inversion region, the bulk of the meteor shower remains neutral. However, if you consider that the larger corpuscles vaporize further down, in the lower wind range, there is a possibility that the formation of the Es layer is a bottom-up phenomenon. In this case, the electrons dating back through the neutral wind inversion belt and would be concentrated by slowing down within the upper wind band. This may explain the quota variance between Es and neutral inversion band.



Notes:

1-<u>Wind formation</u>
Local heating causes a decrease in density because the increased thermal agitation causes particles to move away, i.e., a decrease in local pressure. The less dense particles, being immersed in the Earth's gravitational field, rise to higher altitudes, cooling for expansion. In this way there is a lower main area of low pressure and an upper center of high pressure (tide).
A particle recall is formed towards the low-pressure center (lower zonal wind) and an expansion of particles from the center of high pressure (upper zonal wind).
2-<u>Meteor input</u>
In this part of the Ionosphere (E Region), in addition to the gases that make up the atmosphere, particles of many sizes (meteoric dust, metallic) with great kinetic energy, colliding with the particles of the atmosphere, arrive from outer space. Collisions cause their kinetic energy to be transformed into thermal energy, vaporizing and ionizing them.

The gas present in these areas, has thus been enriched with metal ions and their electrons. In case of major differences, all component particles move like wind, including electrons.

3- Asymmetric formation

About my hypothesis of "asymmetric" formation of the layer, I would put it as an alternative hypothesis to the "symmetric" one, both possible depending on the weather day and the size of the particles. In fact, even in the "symmetrical" hypothesis the electrons must be stopped by the opposite wind, otherwise they would cross and leave. In the symmetrical case they also stop for electrostatic repulsion forces, but for braking from the opposite wind. it is not necessary, for the formation of an Es layer, for electrons to come from above and below simultaneously. They could be lifted by the lower wind and stopped by the opposite upper wind.

Thank you to Dr. Christina Arras of GFZ Potsdam, Section: Space Geodetic Techniques, for her valuable collaboration on sporadic E research. Many pictures and tips in this chapter were provided by Dr. Christina Arras of GFZ.

Summary

- The combined action of ionospheric winds and the magnetic field compresses the ions into thin highly ionized layers. The meteoric dust performs a trigger function.

- The greater summer meteoric flux, plus the intensity of solar radiation, seem to be the key ingredients for the Es (strong correspondence between >> f0Es and meteoric flux).

- The strength of the Earth's magnetic field determines the geographical distribution of the event.

- The annual cycle of Es is connected with the meteoric flow.

- The altitude and local time of the openings are governed by atmospheric tides.

- Solar ionization is another very important factor

Sporadic E: Has a new study found the missing link?

Has the missing link been found in the mysterious history of sporadic E? It would seem so. Thanks to the report of a very good radio amateur, Nuccio Rizzo, IT9RYJ, I became aware of a new study that further digs into the elusive nature of the phenomenon. For us radio amateurs, it is now like the search for the Holy Grail. To go in search of this long chain of mysteries, many years long, I contacted one of the researchers who conducted this study: *"Interhemispheric transport of metallic ions within ionospheric sporadic E layers by the lower thermospheric meridional circulation"*, published in March 2021 in the journal *Atmospheric Chemistry and Physics.* He is Dr. Bingkun Yu, from the Department of Meteorology at the University of Reading-UK. I am convinced that for such a complex, elusive and unpredictable phenomenon, the solution cannot be simple. I would call it a complex system, which is a dynamic multicomponent system. This means that several factors contribute and for the phenomenon to occur, they must act simultaneously, as in a team. Now I have the confirmation. It is a phenomenon that is also linked to the global climatology of the entire planet. The "butterfly effect" comes to my mind: The flapping of a butterfly's wings can cause a hurricane on the other side of the world. With this simple phrase we can summarize the concept that small actions can help generate substantial changes. The idea is that small variations in initial conditions produce large variations in the long-term behavior of a system. The first to analyze the butterfly effect was Edward Lorenz, in 1962. How can we simple radio amateurs understand such complex phenomena? Do not worry. Science comes to meet us. The availability and humility of many scientists that I have contacted personally and who have always shown me great availability. Modern technologies also help to understand phenomena that once it was only possible to hypothesize, without having scientific confirmation. The scientific method (or experimental method) so dear to

Galileo Galilei, is always valid. Indeed, modern technologies have even reinforced it. Sporadic E has been studied for many decades. For us radio amateurs it is a blessing, because it can be used in a positive way for easy and long-range communications, on our bands, but as always there is also the downside. The intense irregularities of the plasma within the E layer, can disturb trans-ionospheric communications to satellites. The Es layer has negative effects on navigation systems. This is one of the reasons why it is studied in great depth by public research institutions and universities. What I have written so far still is valid: The trigger mechanism for the formation of the layer, is the presence of metal ions deriving from meteoric ablation, which remain in the ion state much longer than those of oxygen and nitrogen, ionized by the ultraviolet radiation of the sun. Then the strong ionospheric winds associated with the vertical motions of atmospheric gravitational waves, amass the ions, creating high-density curtains of metal ions. In our latitudes, the phenomenon manifests itself in the summer months. This is in line with annual variations in meteoric flux, which has a higher concentration in the summer months. But this last element of the whole chain, seemed to me the weakest link and the one that left me with the most doubts. In March 2021, this study was published in the journal *"Atmospheric Chemistry and Physics"* of the European Geosciences Union, conducted by an international group of scientists composed of physicists and climatologists of Chinese, English and American nationality. Dr. Bingkun Yu, is a member of this team. This is what Dr. Bingkun Yu told me and that is the missing link of the entire system: They discovered a new phenomenon of a seasonal transport from winter to summer of layers of Es, making use of the data provided by the satellites of the constellation COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate). It is confirmed by long-term ground observations of five ionosonde along the Greenwich meridian at Lerwick (60.13°N, 1.18°W), Slough (51.51°N, 0.60°W), Poitiers (46.57°N, 0.35°W), E), Lisbon

(38.72°N, 9.27°W) and Ouagadougou (12.37°N, 1.53°W) from the Rutherford Appleton Laboratory, UK and five 120°E long ionosondes at Mohe (52.0°N, 122.5°E), Beijing (40.3°N, 116.2°E), Wuhan (30.5°N, 114.4°E), Shaoyang (27.1°N, 111.3°E), and Sanya (18.3°N, 109.4°E) obtained from the Chinese meridian Project, China, like the stations shown in the image below. All 10 stations show a strong summer peak of Es, which appears earlier in low-latitude stations than in mid-latitude stations. This trend can be used to quantitatively estimate the southern ionic velocity of winter-summer interhemispheric transport (about 4.06 ± 0.17 m / s). The formation of the Es layers at mid-latitude occurs through vertical ionic convergence driven by vertical cuts of neutral winds. Extending this original theory of the three-dimensional wind shear, we have shown that this "generalized wind shear theory" with three-dimensional velocity of ions can explain the seasonal variation observed in the layers of Es. Long-lived metal ions have an interhemispheric migration from the winter to the summer hemisphere. The forcing of gravitational waves near the mesopause, drives a mesospheric circulation from summer to winter and a reverse circulation from winter to summer in the lower thermosphere. Between ~95 and ~115 km, the seasonal horizontal transport of ions within the Es layers, is caused by the lower thermospheric southern circulation from winter to summer. The global distribution of the Es layers and the latitudinal and annual variations in the Es layers are related to the large-scale horizontal transport of metal ions. In other words, it is a large-scale horizontal movement of long-lasting metal ions, also confirmed by combining the simulations of the WACCM (Whole Atmosphere Community Climate Model) climate model with the observations of a chain of ground stations over a period that goes from 1975 to 2016, therefore over a prolonged period. This simulation also highlighted the importance of the circulation that occurs between winter-summer between the hemispheres at the level of the thermosphere and the ionosphere.

The new discovery

In summary: Seasonal variation of the Es is closely related to the transport of ions caused by circulation in the lower thermosphere from winter to summer. From February to April the Es moves from both hemispheres to the equatorial zones. From May until July, the Es moves north and reaches its summer peak in our hemisphere. From August to October, however, the Es begins to migrate back to the equator, and with this reverse process then determines the maximum peak of Es in the summer months of the southern hemisphere. Perhaps the long history of sporadic E is not yet definitively closed, but I think we have taken another step forward, towards understanding the whole mechanism. The complexity is due to the fact that for this phenomenon, the global climatology of the entire planet comes into play. Do you remember the famous "butterfly effect"?

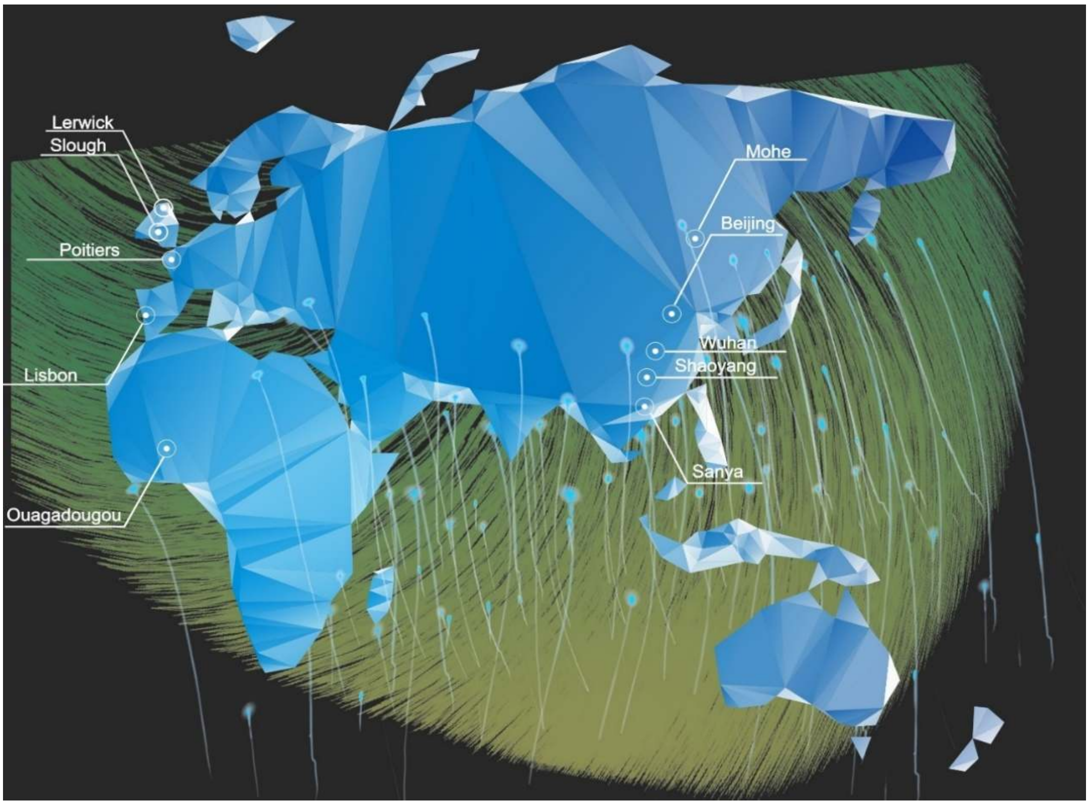


Fig. Artistic image, created by Dr. Bingkun Yu, summarizes the main results of the study “Interhemispheric transport of metallic ions within ionospheric sporadic E layers by the lower thermospheric meridional circulation", published in the journal Atmospheric Chemistry and Physics.

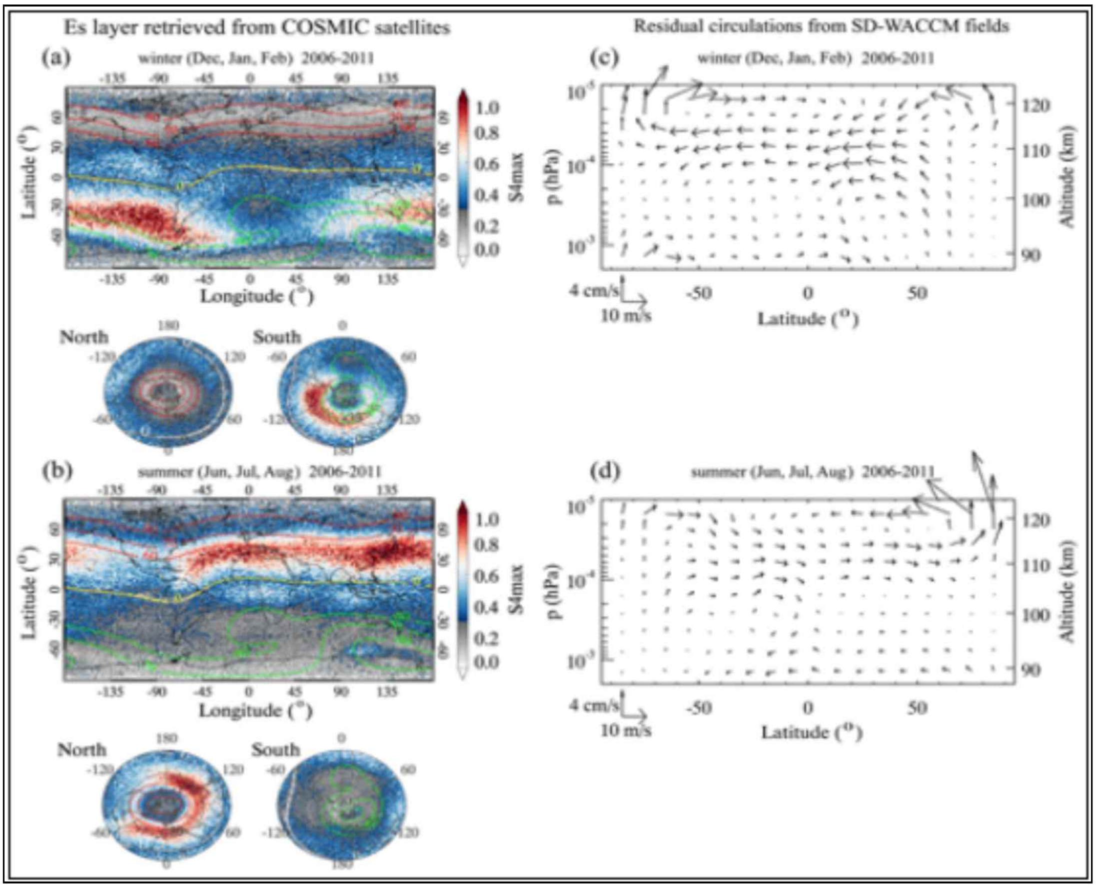


Fig. Global distributions of the mean Es layer intensity represented by the S4max index from COSMIC are shown in (a) and (b) for the winter (December, January, February) and summer (June, July, August), respectively, between 2006 and 2011, detected from COSMIC multi-satellites with a resolution of a 1 ∘ ×1 ∘ . The red and green curves stand for the geomagnetic latitude contours of 60, 70, and 80 ∘ in the Northern Hemisphere and Southern Hemisphere, and the yellow curve represents the geomagnetic Equator. The mean residual circulations are calculated for winter (c) and summer (d) using the SD-WACCM4 (2006–2011). There are three circulation cells: mesospheric circulation, lower thermospheric circulation, and thermospheric circulation. Below 95 km, the summer-to-winter mesospheric circulation is driven by gravity-wave forcing. Between 95 and 115 km, the winter-to-summer lower thermospheric circulation is driven by gravity-wave forcing that is in the opposite direction to that which drives the mesospheric circulation. Above 115 km, the solar-

driven thermospheric circulation is a summer-to-winter circulation.

Credits for this chapter: Yu, B., Xue, X., Scott, C. J., Wu, J., Yue, X., Feng, W., Chi, Y., Marsh, D. R., Liu, H., Dou, X., and Plane, J. M. C.: Interhemispheric transport of metallic ions within ionospheric sporadic E layers by the lower thermospheric meridional circulation, Atmos. Chem. Phys., 21, 4219–4230, https://doi.org/10.5194/acp-21-4219-2021, 2021.

Is possible to predict sporadic E?

A prediction model based on the meteoric nature theory of sporadic E

Introduction

Heinsemberg, in his uncertainty principle said: Of a particle you can know speed or location, not both. This could also apply to the prediction of the sporadic E.
We have recently developed research showing that the formation of the sporadic E layer, at temperate latitudes, has origins that come from outside the earth.
Studies conducted in recent years by many Geophysics Institutes have confirmed the presence of a considerable amount of meteoric pulverization within region E, this pulverization is accumulated in thin super dense layers generated by the jet stream.
The sporadic E layer is caused by the dispersion of metal ions derived from meteorite fusion that continuously affect the Earth's atmosphere.
It is not the only cause, but meteoric ablation acts as a trigger.
Thus, the propagation is due to the combined action of:

- *Ionospheric Winds*
- *Solar flux*
- *Atmospheric gravitational waves*
- *Meteoric ablation (having trigger function)*

Theory

In the E region there are strong horizontal winds, these intense winds move within the ionosphere and are separated by a few kilometers of altitude. Their action, combined with the action of gravitational waves of tropospheric origin and the Earth's magnetic field, pushes the gaseous ions within this area by accumulating them in layers that form ionized clouds. As a rule, the extent of these ionized patches is not wide, it can be 50 to 100 kilometers in diameter (at temperate latitudes), their development on the surface is a few thousand square kilometers, the concentration of electrons per cm3 is much higher than in the ordinary E layer. These east-west winds in the E layer, move vertically because of gravitational waves and in the presence of the Earth's magnetic field compress the ions into thin high ionization amassments, for the accumulation of ions, we need metal ions such as magnesium ions (Mg+), Iron Ions (Fe+) and Nickel (Ni+), because their recombination capacity is slower than other ions and this therefore allows massing in dense and thin layers.

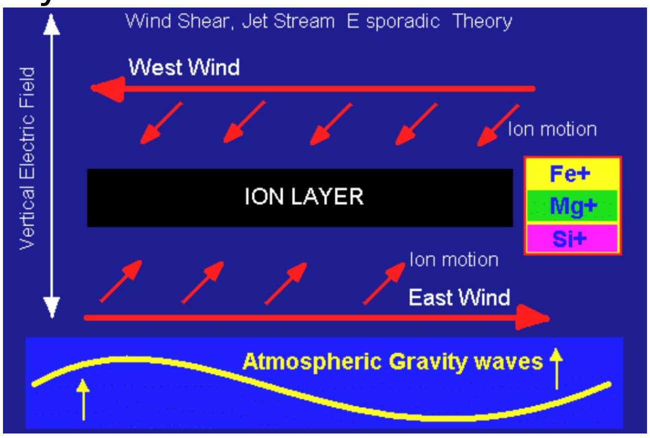


Fig. Simplified diagram of the massing of ions, especially metallic, due to the action of jet stream and atmospheric gravitational waves in the presence of the Earth's magnetic field.

Ions are atoms or groups of atoms with an electric charge from neutral atoms or groups of atoms that have lost or purchased one or more electrons (recombination process). Recent measurements have revealed that Es curtains have a high content of metal ions (Fe+ and Mg+), as well as

O_2^+ and NO^+, the main and dominant ions present within E region. Metal ions are the residual left by meteoric dust entering the Earth's atmosphere, captured by the earth's gravitational force. Meteoric ionization is not the only cause but should have a catalytic function in the entire mechanism, especially for the more intense Es phenomena (the one affecting the higher frequencies 50 MHz, and above all 144 MHz). The intensity of the Es event depends on the residual ionization of the layer, the number of heavy ions present (related to meteoric precipitation) and the strength of the ionospheric winds, especially the amplitude of the wind speed change index with height, responsible for ionized layer.

Atomic composition of meteorites

The atomic composition of meteorites entering the Earth's atmosphere is shown in the table below. The dominant metal elements are iron, magnesium, nickel and aluminum.

Meteorites can be of two types, ferrous meteorites or rocky meteorites (Iron meteorite, Stony meteorite). For the formation of sporadic E, both compete even if the ferrous meteorites supply the greatest contribution of metal atoms. When they pass through the atmosphere, meteorites warm up to temperatures above 3000° Fahrenheit and in the case of larger components they emit light. Heating does not occur by friction, as one might commonly think but it is a phenomenon called dynamic pressure. A meteorite compresses the heating air and in turn warms the meteorite. The intense heat vaporizes most of the fragments, the larger fragments become visible up to about 90 kilometers away. Some large meteorites cause a brighter flash called fireball; it is a real explosion that can be heard up to 50 kilometers. Destruction in the atmosphere depends on its composition, speed and angle of entry. A faster meteorite at an oblique angle undergoes the largest force. Iron-composed meteorites withstand dynamic pressure better than rocky meteorites and disintegrate at lower altitudes of about 10

to 12 kilometers, where the atmosphere becomes denser. Meteor material entering the Earth's atmosphere can reach a total amount of several tons every day. They usually have strange shapes and are very heavy in comparison to their greatness.

Typical Composition:

Iron Meteorite	Stony meteorite	
Iron 91 %	**Oxygen**	36%
Nickel 8.5%	**Iron**	26%
Cobalt 0.6%	**Silicon**	18%
	Magnesium	14%
	Aluminum	1,5%
Source:	**Nickel**	1,4%
Encyclopaedia Britannica	**Calcium**	1,3%

Fig. Composition of meteorites. The dominant metal elements are iron, magnesium, nickel and aluminum. Meteorites can be of two types, ferrous meteorites or rocky meteorites (Iron meteorite, Stony meteorite).

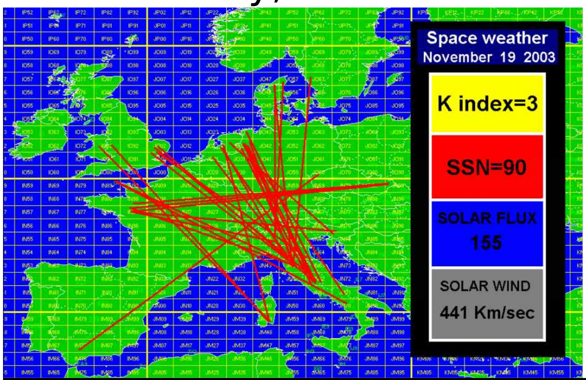
Variations in the meteor flux

It is estimated that a few tens of billion micro-meteorites with a diameter of one tenth of a millimeter enter the atmosphere daily at a speed of the order of 100,000 km/hour, not to mention the largest particles, and the ablation takes place at the height of E layer, where the chances of collision with the gas molecules are greater (due to the high density'). This flux of meteorites that enters the atmosphere daily is not constant. It varies depending on the hours of the day, and the season as well as from year to year. We know that the phenomenon of sporadic E is concentrated in the summer months and this seems confirmed by the trend of the diagram showing the annual variation, the meteor shower is greater in the months from June to September, coinciding with the statistically best months for sporadic E openings. It cannot be just by chance that the most frequent and intense openings of Es propagation are concentrated in a few months, a link, although it is not the only explanation.

Opening of sporadic E of November 19, 2003

As an example, we report the opening of sporadic E on Wednesday, November 19, 2003, in central Europe, which

raised the MUF to 144 Mhz. And therefore, with the formation of hyper-dense sporadic E, as reported by the observations of IZ2ESV, Tony de Longhi.
The opening took place in the early hours of the afternoon, on the 10 meter band, with signals coming from Northern Germany, the south of England and Belgium.
The stations were located at about the same latitude, with powers of less than 100 watts and vertical antennas or G5RV. At the same time, it was clear from the cluster that there was an important reflection area between Italy and Germany on the 50 MHz and between the United Kingdom and Germany, in 144 Mhz.



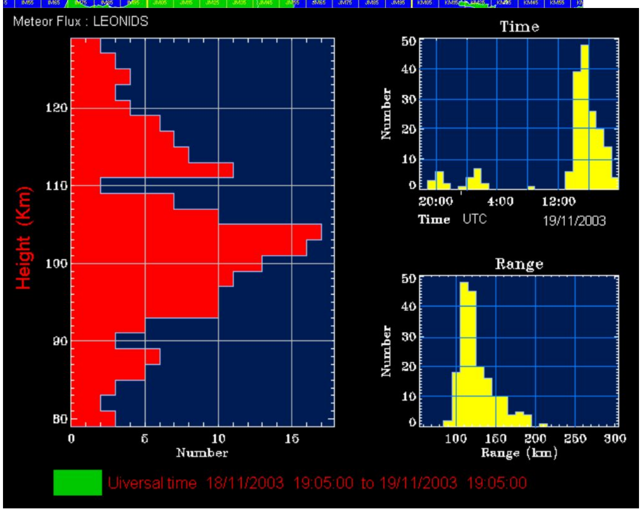


Fig. Real-time schematization related to the distribution of meteorites with the height and monitoring of the flux of meteorites over time (peak after 13 UTC).

Frequency dependency

Sporadic E events in 144 MHz are rare, about 5 % of total Sporadic E events.

Therefore, the Es prediction becomes more difficult as the frequency increases. In the summer months the propagation openings in 28 MHz and in 50 MHz, at the right times, are daily, but is different in 2 meter band. To send rays of 144 MHz back to the ground, highly ionized curtains are needed so, a sporadic hyperdense E is required. The hyperdense sporadic E, should take place at meteoric peaks of activity, as showed in the event mentioned in these pages, of November 19, 2003, where the peak of the Leonids allowed an opening that raised the MUF up to 144 Mhz.

Dependence on solar activity

The openings are concentrated in the hours of light, and therefore solar radiation undoubtedly plays a significant role, although, especially in the winter months, nocturnal ES phenomena can occur.

The eleven-year cycle of the sun, on the other hand, does not seem to directly influence the formation of Es. A long-term statistic has shown that there are no very evident connections between high solar activity and Es openings, although there appears to be a higher incidence of openings in periods of low solar activity, this may be due

to greater geomagnetic stability in periods of low solar activity. This confirms the importance of meteoric ablation on the dynamics of the complex mechanisms governing the formation of layers.

Geomagnetic activity

Always starting from a long-term analysis, we have reconstructed a map of the Es openings and connecting them with geomagnetic activity. The conclusion is that sporadic E occurs predominantly (more than 90% of cases) in the presence of a quiet geomagnetic field, statistical analysis suggests that the optimal geomagnetic indices are Kp less than or equal to 3 and ap index less than or equal to 17.

Time distribution of meteors

Time distribution and height, of the peak of the Leonid meteor shower (Nov.2003) The maximum distribution takes place between 90 and 110 kilometers. The data collected by the radar meteors seem to correspond chronologically with the openings Es occurred on the bands 28-50 and 144 MHz.

Jet Stream Action

A significant role in the complex mechanisms of sporadic E cloud formation should be the Jet Stream. It is a narrow, strong and concentrated wind current along an almost horizontal axis, located in the upper troposphere and the stratosphere, characterized by a strong vertical and lateral gradient of wind intensity that has one or more speed maxims. Typically, the length of a jet stream is several thousand kilometers, its width a few hundred kilometers and its height a few kilometers. The wind speed is normally greater than 60 kts, the vertical Shear is 5/10 meters per second per kilometer, the horizontal shear is 5 m\sec per 100 km. The jet stream can be depicted as a fast-flowing river of air (west to east). It reaches a development of 4000-5000 km with a size of about one hundred km. It has a circumpolar character and in its path

alternates speed maxims with regions with lower speeds. The width of areas with speeds of more than 100 kts is about 200 km. The speed highs reached by the jet take on lower values in summer than those assumed during the winter; its position also changes with the season: in summer it is located at higher latitudes than winter latitudes. Although we do not have precise studies on the subject, jet stream movements certainly have an impact on the geographical distribution of Es events, further studies are needed to better understand this mechanism.

Ionospheric winds and gravity waves

Atmospheric gravitational waves (not to be confused with gravitational waves related to Einstein's theory of relativity) they should contribute to the formation of Es curtains by acting in correlation with ionospheric winds, contributing to the accumulation of ions until the formation of ionized clouds.

AGW are neutral high wavelength pressure waves (with a period T ranging from 10 to 180 minutes) that extend within the thermosphere and the mechanism that generates the wave is an oscillation caused by the displacement of an air cell that is relocated to its initial position due to gravity and the movements that generate it are varied in nature , in the low atmosphere they are activated by different meteorological phenomena such as temporal formations, action of winds on the Earth's surface, cyclonic formations and instability' caused by jet stream, while at high latitudes AGW. are found more in the upper atmosphere and have causes associated with joule heating, Lorentz forces, and particle precipitation related to the magnetic field and coming from the sun. The different level of insolation between the two hemispheres leads to a strong thermal imbalance which generates a wide circulation of currents in the lower ionosphere, in the summer hemisphere, so warmer is created an ascensional current, compensated by a current in the opposite direction in the cold hemisphere, this is the dynamic that generates the strong ionospheric winds These oscillations

at temperate latitudes, occur in the low atmosphere (limits of the troposphere) and consequently propagate within the Mesopause (about 90 kilometers above sea level) , up to the thermosphere, fully involving region E. The state of agitation, for example, of the peak of a temporal formation is strong and this agitation can transmit gravitational waves to the Mesosphere, within which there are rushing winds, even of 300 km/h.

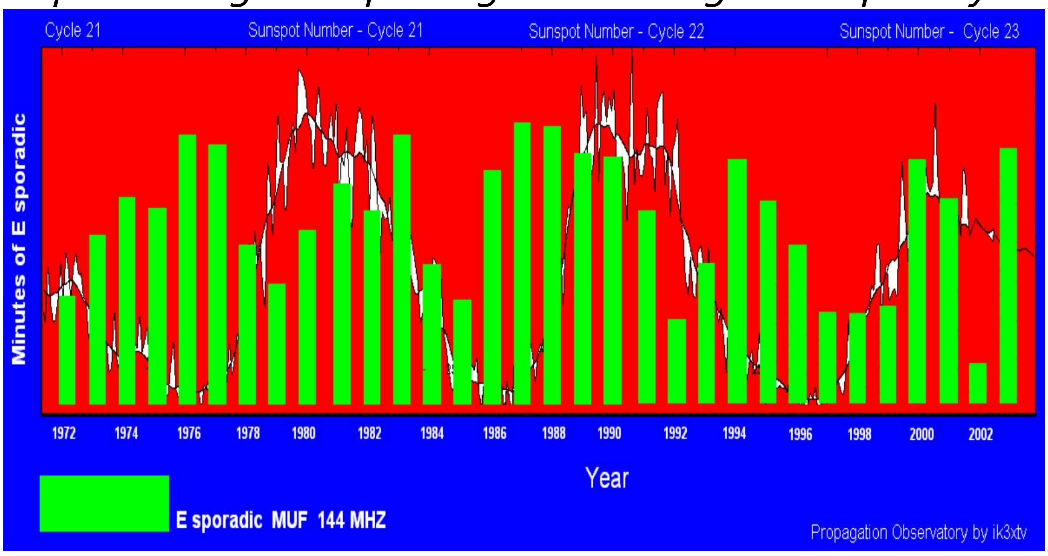
Some other information about sporadic E and solar activity

The relationship between the formation of the Es layer and solar activity is not yet entirely clear.

A long-term analysis of the ratio of the K index to the geomagnetic activity conducted at 50 MHz revealed a greater incidence in the formation of Es when geomagnetic activity was low, in the presence of high K values and therefore in the presence of geomagnetic storms, the propagation deteriorated rapidly. A situation of magnetic stillness is always synonymous with good propagation and this also seems to apply to Es propagation. In fact, a calm situation corresponds to a uniformity of stratifications within the ionosphere, which on the one hand, reduces absorption and on the other, allows a greater probability in the formation of Es curtains, also in the presence of an agitated magnetic field, the actual height of a layer undergoes continuous fluctuations in height, the density of electrons per cm3 decreases due to dispersion and turbulence, deteriorating those favorable conditions for reflective cloud formations. The ratio of Es clouds to the sunspot cycle is less clear, although statistical observations in the long term, suggest that openings are more frequent in the low periods of the one-decade cycle (small number of spots). In periods of high solar activity, the solar flux increases by improving the level of ionization of F layer and E layer normal, however this does not seem to have a direct impact on propagation for E sporadic.

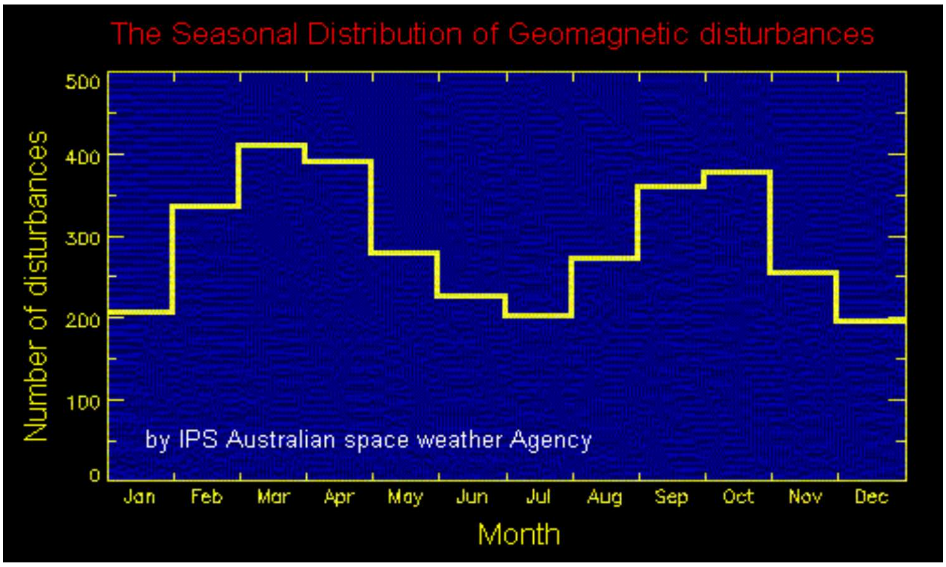
Forecasting model
Starting from the belief of the meteoric origin of sporadic E and based on a long-terms statistical studies (from 1970 to 2003) of sporadic E openings on the VHF bands (50 and 144 MHz) I have developed a model that should allow a prediction for a phenomenon that is unlikely to predicted.

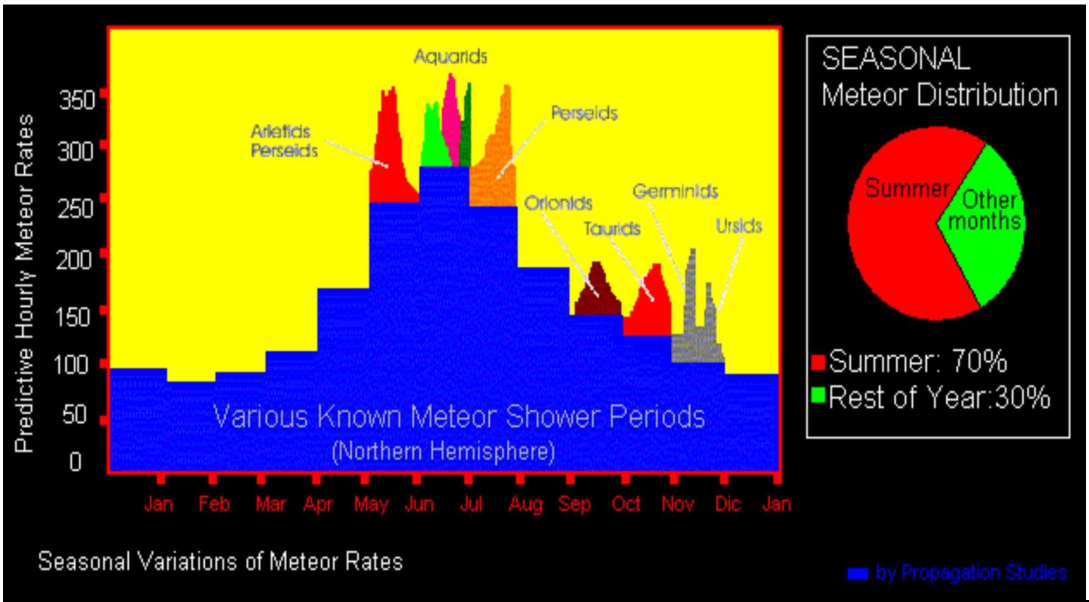
- *Geomagnetic activity must be low, Kp index not exceeding 3.*
- *Check the calendar of meteor showers, near the maximum peaks the chances are greater.*
- *Check the time of day, taking as a reference the two tables (winter and summer) of the opening. possibilities according to the local time.*
- *Consider the month of the year, referring to the percentage incidence using the Es opening table based on months.*
- *In the summer months, especially June and July the possibilities are extremely high.*
- *Consider the frequency used as the possibilities decrease as the frequency increases, see table of the percentage of openings according to frequency.*



The graph at the top is a statistical processing of the total openings of sporadic E with MUF up to 144 MHz (green bars), compared with the trend of the cycle of sunspots, the statistic covers a period of 30 years and develops over

almost 4 solar cycles. The long-term analysis confirms a higher incidence of openings in periods of low solar activity (due to quiet geomagnetic field), but the trend is not so clear and marked.





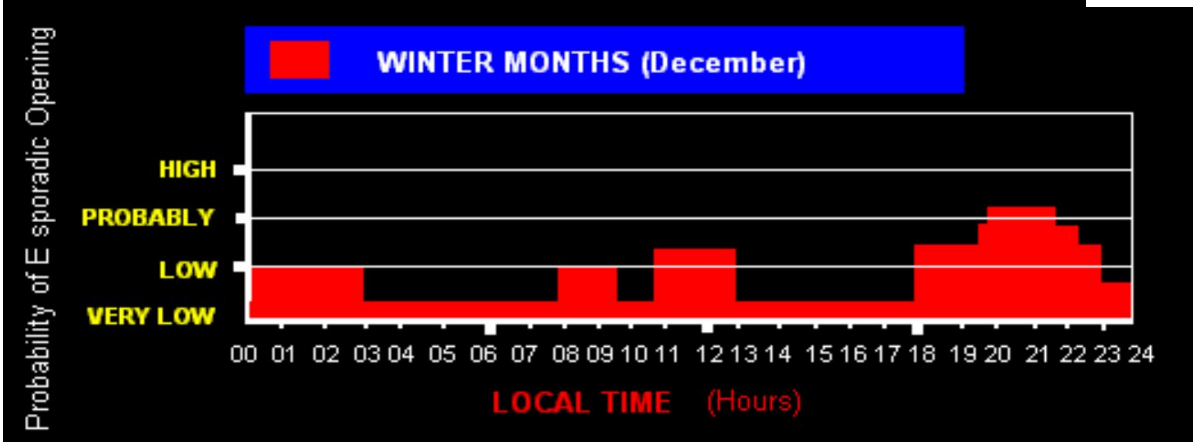
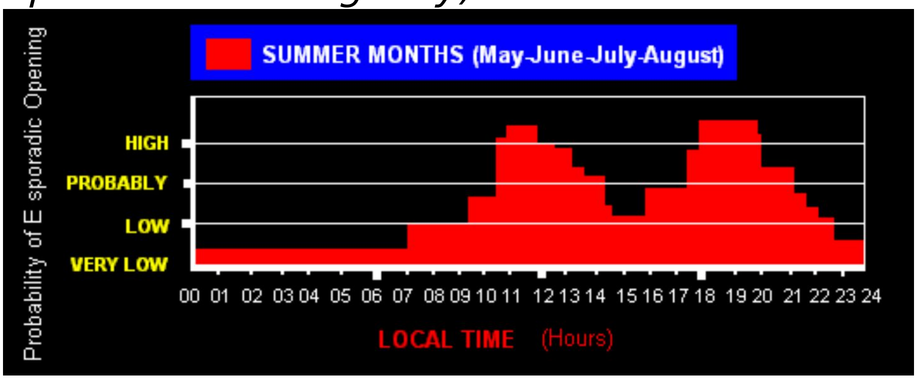
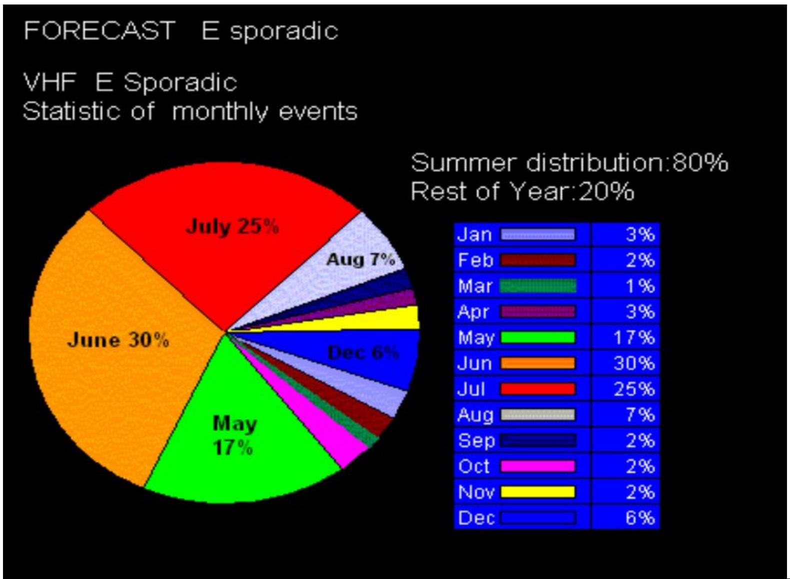
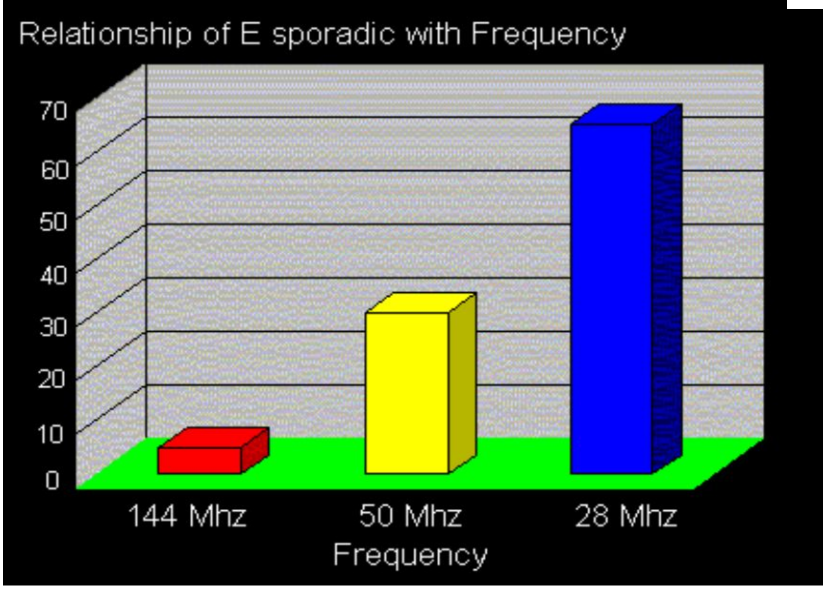


Fig. Seasonal distribution of geomagnetic disturbances. In the typical months of Es, the incidence of disturbances is lower than confirmation of the concentration of Es openings, in the summer months. (Source: IPS Australian Space weather Agency).







Final considerations

The model I have developed so far, it is not to be considered a foolproof manual, but a useful tool to try a prediction based on the belief of the meteoric origin of ES and supported by a whole series of statistical research supporting this model. However, many areas of further research and development remain, the function of

atmospheric gravitational waves is important, also we have noticed that the Es clouds are located, at least in Europe, always in the same areas, or not far away. This frequency should be linked to the presence of anomalies of the Earth's geomagnetic field at these geographical areas that could favor the thickening of the metal plasma precisely in these areas. These magnetic anomalies are more numerous than is believed, only on Italian territory, for example, at least six areas with large magnetic anomalies are located.

Sporadic E formation and meteorites
(Some other studies)

Let us see a few more pages on the Sporadic E. We have seen that it has origins that come from outside the earth, because it is caused by the dispersion of metal ions derived from meteorite fusion that continuously affect the Earth's atmosphere. This is not the only cause, but meteoric ablation acts as a trigger. Thus, the propagation is due to the combined action of:

- Ionospheric winds
- Solar flux
- Meteoric ablation (having trigger function)
- Atmospheric tides (having modulation function)

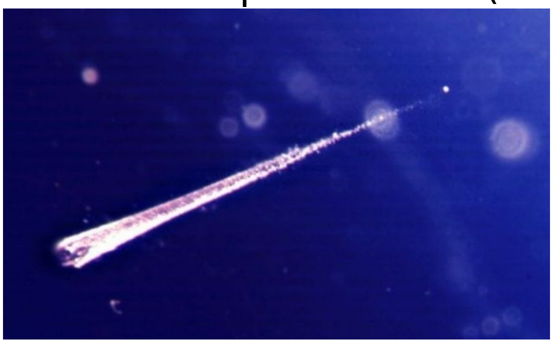


Fig. Wikipedia source: "A 1.5 mm long impact track of a meteoroid captured in aerogel exposed to space by the European Retrievable Carrier (EURECA) spacecraft launched by STS-46 and recovered by STS-57. The wide

end (open end) of the "carrot" is the location of hypervelocity entry into the 0.05 g/cc aerogel. As the particle is slowed by the aerogel the track narrows to a point. The 10-micron projectile is seen at the tip of the "carrot". (Image NASA-Wikipedia public domain).

How the ionized layer is formed
Within the E region there are strong horizontal winds, these strong winds move within the ionosphere and are separated by a few kilometers of altitude. Their action, combined with the action of gravitational waves of tropospheric origin and the Earth's magnetic field, pushes the gaseous ions within this area by accumulating them in layers that form ionized clouds. As a rule, the extent of these ionized patches is not wide, it can be 50 to 100 kilometers in diameter (at temperate latitudes), their development on the surface is a few thousand square kilometers, the concentration of electrons per cm3 is much higher than in the ordinary E-layer. These east-west winds within E layer, move vertically as a result of gravitational waves, and in the presence of the Earth's magnetic field compress the ions into thin high ionization amassments, for this massing of ions to be possible, metal ions such as magnesium ions (Mg^+), Iron Ions (Fe^+) and Nickel (Ni^+) are needed, as their recombination capacity is slower than other ions and this therefore allows massing in dense layers and thin. Ions are atoms or groups of atoms with an electric charge from neutral atoms or groups of atoms that have lost or purchased one or more electrons (recombination process). Recent measurements have revealed that Es curtains have a high content of metal ions (Fe^+ and Mg^+), as well as O_2^+ and NO^+, the main and dominant ions present within region E. Metal ions are the remnant left by meteoric dust entering the Earth's atmosphere captured by the earth's gravitational force. Meteoric ionization is not the only cause but should have a catalytic function in the entire mechanism, especially for the more intense Es phenomena (the one affecting the higher frequencies 50 and above all 144 MHz). The

intensity of the Es event depends on the residual ionization of the layer, the number of heavy ions present (related to meteoric precipitation) and the strength of the ionospheric winds, especially the amplitude of the wind speed change index with height, responsible for ionized storage.

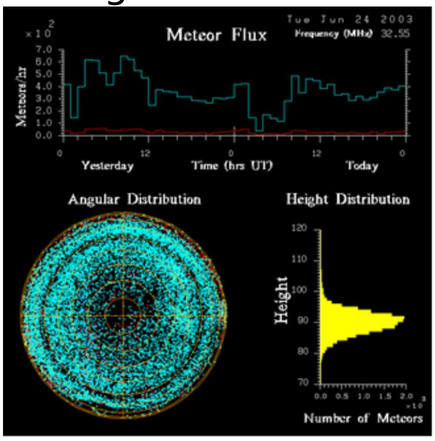
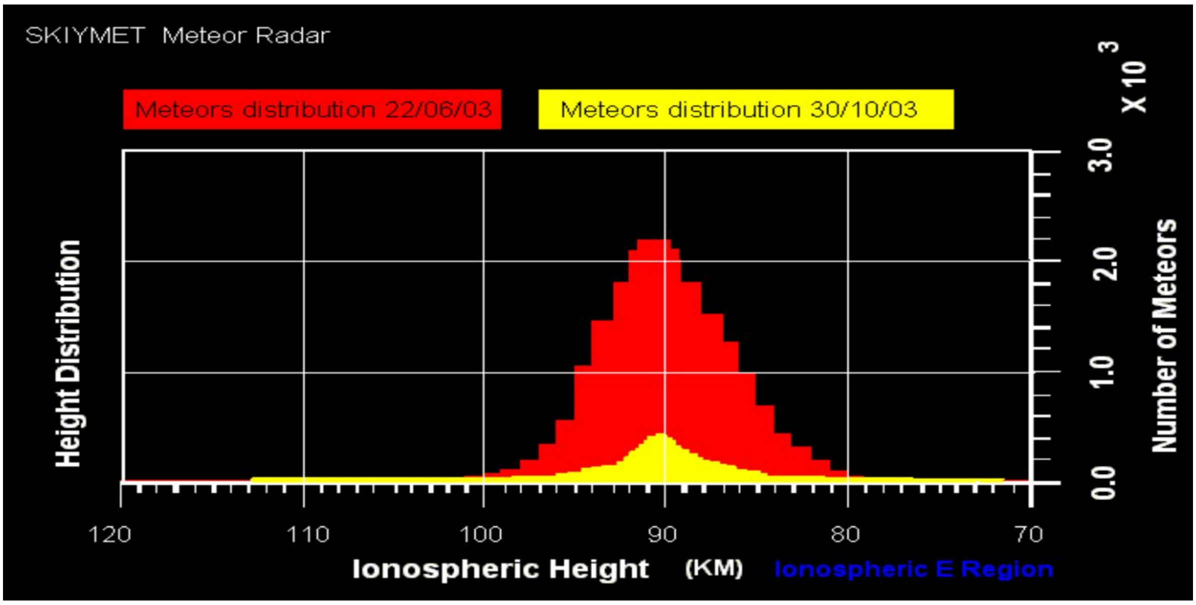


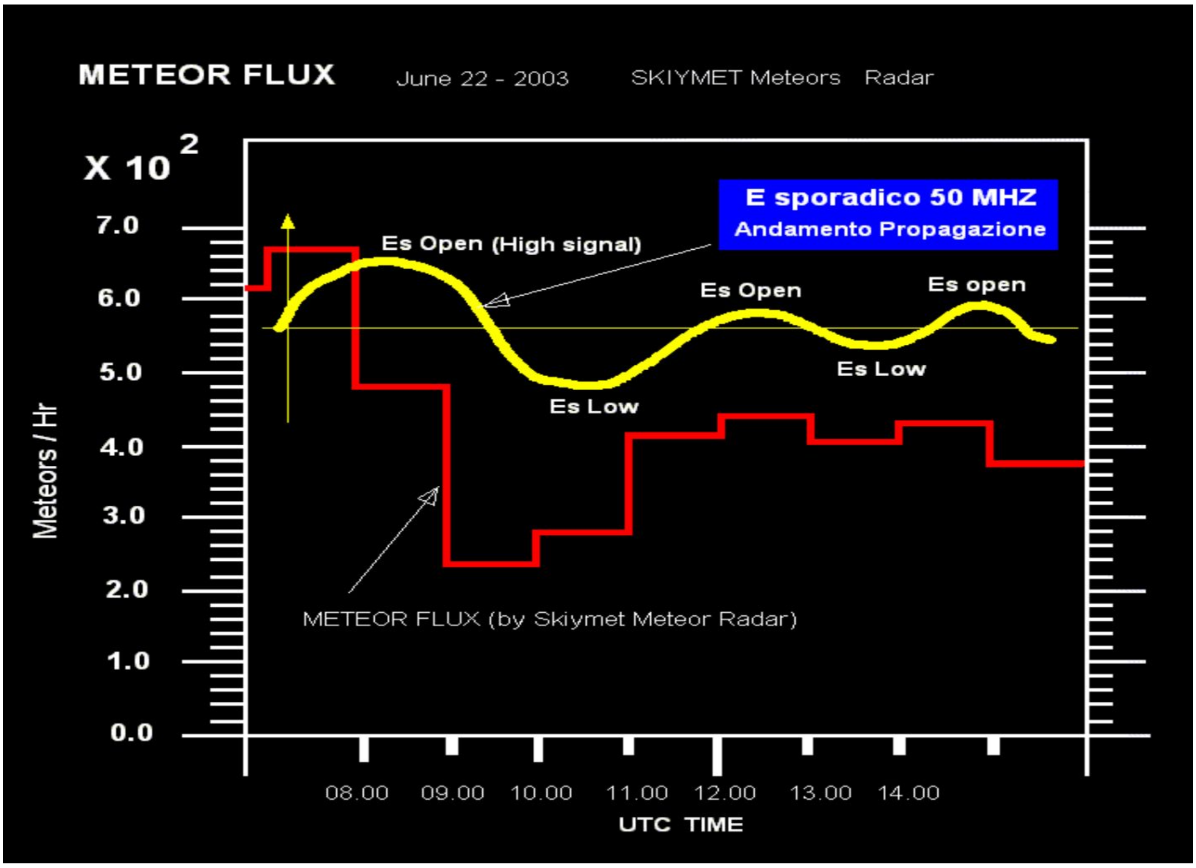
Fig. Diagram of the meteor flux of 24/06/2003, corresponding to a good sporadic E opening in 50 MHZ. From the curve illustrating the distribution of meteorites with height, we can see that the greatest concentration is between 80 and 100 kilometers in region E. (Image Collm's Radar meteor in Germany).

Data collection



I took as a reference the IARU contest on the 50 MHz of June 22, 2003, since a systematic observation on propagation for sporadic E, was present. Thanks to the data available from SKIYMET METEOR RADAR, I was able to compare the meteor flux of 22/06/2003, with the flux of a day taken as a sample, without any opening of E sporadic. This day was 30/10/2003. The data are shown in the diagram at the top of the next page, where the red curve refers to the June 22 flux and the yellow curve to October 30. I compared data from other openings with other days, and the results is similar. The difference in meteoric flux is considerable and seems to confirm that the phenomenon of meteorites is the determining factor for the formation of Es.

Fig. Data from SKIYMET METEOR RADAR, comparison between the meteor flux of 22/06/03 (Good opening of Es on 50 MHz) and the flux of 30/10/03, when Es propagation was completely closed.



Furthermore, the propagation trend during the day of 22/10 was not constant, but the quality of the opening and therefore of the signals underwent a cyclical trend that seems confirmed by the constant meteoric flow as shown in the figure below, the trend of propagation follows the trend of the quantity of meteorites entering the atmosphere.

Fig. Comparison between meteorite flux and Es propagation level

Geomagnetic anomalies

There are studies which try to explain how the distribution of sporadic E is not entirely random, but there are favorable areas, where there seems to be a greater concentration of the Es events. One of the theories, developed by some radio amateurs in the past, is attributed to geomagnetic anomalies of the Earth's crust, able to thicken and favor the formation of Es curtains in certain geographical areas. Such a hypothesis would be very well coupled with the meteoric nature hypothesis of

Es. The metal dust could easily be concentrated in areas where these anomalies exist, contributing fundamentally to the formation of clouds. I managed to recover maps that show the areas where geomagnetic anomalies are concentrated. It could be interesting to create a statistical model of Es events, check their geographical distribution and compare them with such maps. However, this is a difficult and demanding job which also takes a long time. A statistical study, to be reliable, should be carried out in the long term, perhaps comparing even several detection samples.

Atmospheric weather conditions and Propagation

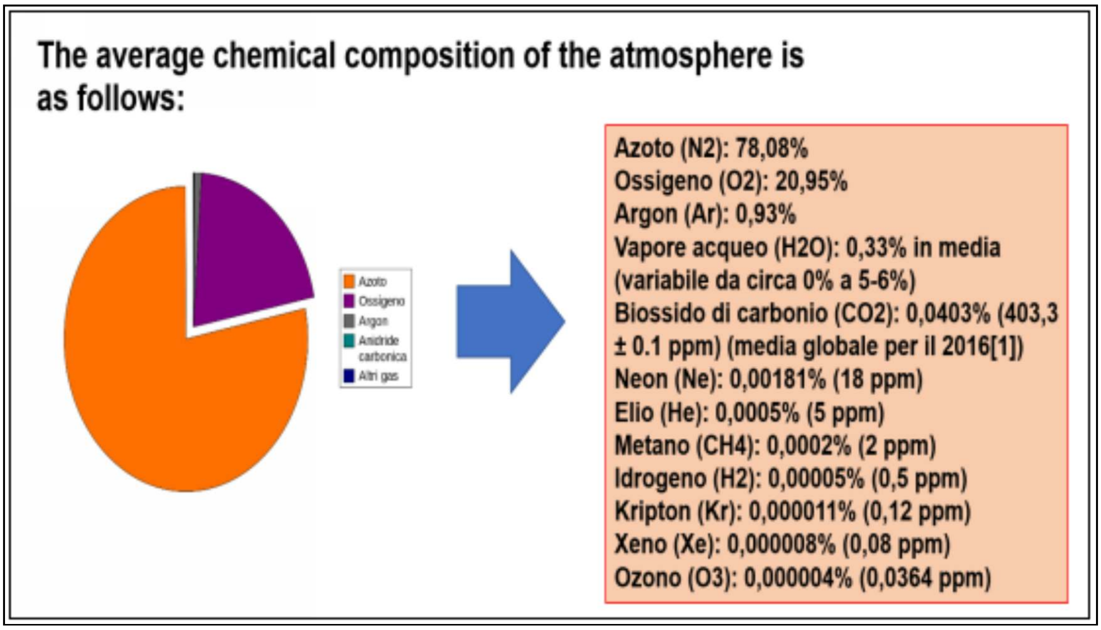
Influence of meteorological phenomena in the ionospheric radio propagation

Introduction

This research aims to relate the propagation of radio waves with the meteorological situation, to try to understand what the correlations between troposphere meteorology and the upper layers of the Earth's atmosphere. As we know, radio waves have completely different behaviors as the frequency changes, so we must take that into account, and relate everything to the frequency of the reflected wave. All weather phenomena occur in the troposphere, so at heights up to about 10-12 km (temperate zone), the troposphere and ionosphere are not two completely distinct but dynamically two linked things, also the radio waves that start from the transmitting antenna must cross both layers so a certain relationship and influence must be there, whatever the frequency of the incident wave. In addition, recent studies confirm the influence that atmospheric gravity waves generated by tropospheric phenomena can have on the atmosphere and therefore also on radio propagation.

Atmospheric and Ionosphere physics

The Earth's atmosphere is limited in size, this outer layer of water vapor and gas enveloping our planet is very thin compared to the physical size of the earth, so it can be deduced as the equilibrium of atmosphere. it is delicate and may be influenced by the earth below, by the emission of energy from the sun and therefore by the magnetosphere. Temperature, pressure, solar radiation flux, composition, vary with altitude, but areas within the atmosphere can be identified, where these values vary very slowly or remain fixed, they are the so-called "spheres", i.e. areas with almost constant characteristics, separated by areas of discontinuity' where the values undergo a sharp variation, these are very thin areas called "pauses".



Ionosphere

The Ionosphere is the upper part of the earth's atmosphere and extends from about 60 to 1000 km above sea level, the presence of high amounts of ions and free electrons influences the propagation of radio waves passing through it. Free ions and electrons are produced by gas molecules split by sunlight.

The sources of ionization are as follows:

- *Solar radiation: X-rays and UV ultraviolet radiation.*
- *Cosmic Rays (GCR).*
- *Energetic particles from the Sun and van Allen belts.*
- *In the lowest atmosphere, radioactive radiation from rocks.*
- *Meteoric ablation in E region.*

UV rays and X-rays provide the most important source of photoionization above 60 km of altitude, up to the highest altitudes, F1 and F2 region around 400 km high. The deep penetrating part of UV rays (low wavelength, less than 175 nanometers) and X-rays, meets E layer at 90-140kms and finally, D layer at 70-90km. Above 100 km. ionization is caused by solar X-rays, where electrons and ions are separated by a mixture of electrons, ions, and particles of neutral gas called Plasma. Ionization makes air electrically conductive, resulting in electric currents flowing within the Ionosphere, and radio waves can be reflected or absorbed. During the night, residual ionization remains as well as a slight source of continuous ionization caused by dispersion from the illuminated side of the earth, stellar radiation (affecting E region) and galactic cosmic rays (affecting D region).

Troposphere

The troposphere is the lowest layer of the Earth's atmosphere, it extends from the earth's surface to about 10 km above sea level in temperate zones. The thickness increases at the equator and decreases at the poles due to temperature differences (5-6 km. above the poles, 15-18 km above the equator), warmer air due to expansion occupies a greater space than cold air.

The chemical composition of the Troposphere is as follows:

-Nitrogen 75.5%
-Oxygen 23.1%
-Carbon dioxide 0.046%

-Other Gases 0.074%
-Indeterminate water vapor

The word Troposphere comes from the Greek "Tropos" which means variation, precisely because within this sphere we find the greatest pressure and density values, as well as the largest variations.
Within the Troposphere, all meteorological phenomena happen, such as clouds, precipitation, lightning and the temperature decreases with the increase of the altitude of about 6° C per kilometer. Troposphere contains 90% of the Earth's atmosphere and 99% of the water vapor; it is formed for 23% of molecular oxygen (O_2), 75% of molecular nitrogen (N_2) and are present in negligible quantities (1-2%) other gases as well.

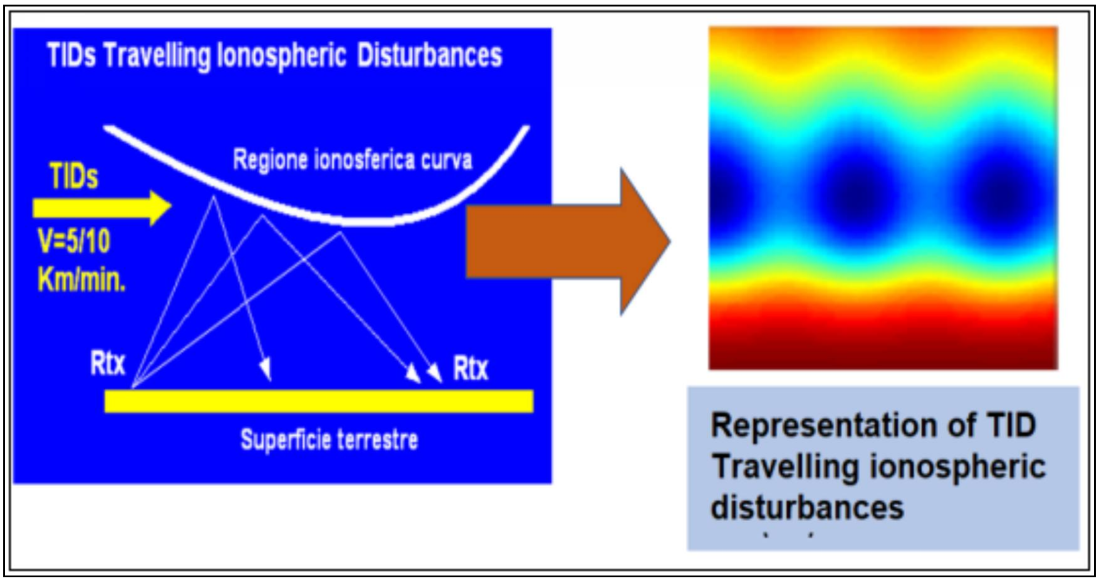
Meteorological effects
The latest scientific research proves an interaction between the Ionosphere and the lower atmosphere. The aeronomy and dynamics of the absorbent D layer, the abnormal absorptions of radio waves in the ionosphere, the formation and structure of the Es, the ionospheric currents, as well as the structure of F region, should be studied in correlation with the thermodynamic situation of the lower ionospheric layers and therefore also in relation to what happens in the troposphere.
This is due to the propagation from the troposphere and stratosphere to the ionosphere of a wide spectrum of atmospheric, acoustic and gravitational internal waves as well as possible gravitational influences of the moon (tides). Wind movement and circulation, turbulence and currents occur not only within the troposphere but occur up to the height of the Ionosphere.

The interaction force depends on the characteristics of atmospheric circulation, the intensity and origin of the waves. The theory of the influence of ionospheric winds, gravitational waves associated with the action of weather conditions in the troposphere should therefore have some influence on the ionospheric layers and therefore also influence the propagation of radio waves in the ionosphere.
The ionosphere and troposphere are both dynamically and chemically linked.
At low and central latitudes on the illuminated side of the earth, for example, thermospherical neutral winds move ionospheric plasma across the lines of the geomagnetic field, creating an atmospheric dynamo that generates a whole series of ionospheric currents, and the equatorial electrojet, a strong current is formed from the illuminated side to the dark side entering E region, along the geomagnetic Equator.

TIDs - Travelling Ionospheric disturbances
These are high-density electronic structures that propagate horizontally within the ionosphere at a speed of 5 to 10 km/min. with a well-defined direction. They originate in auroral zones because of solar events or because of gravitational waves caused by weather events. These ionospheric disturbances can have negative effects on the reflections of radio signals, especially they cause evanescence since they can form inclined ionospheric regions (as shown in the figure in the next page) due to multiple paths that generate the evanescence of the signal, moreover TIDs cause the variation in phase, amplitude, polarization and angle of arrival of the electromagnetic wave. Two distinct types of mobile ionospheric disorders can be distinguished:

-Large-scale TIDs, having 1000 km of wavelength, which move from the poles towards the equator and generated by auroral activity

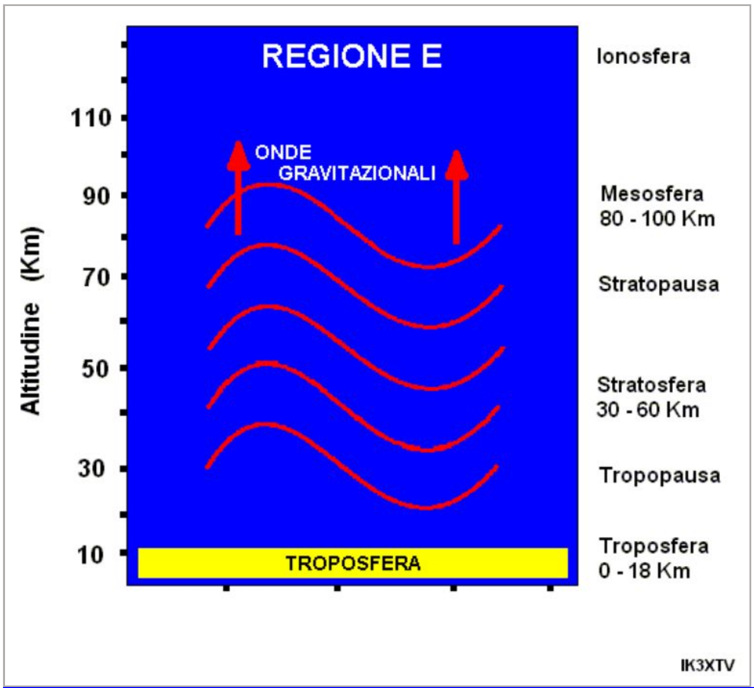
-TIDs on a medium scale, having a few hundred or km of wavelength and generated by temporal phenomena and atmospheric gravitational waves.



Ionospheric winds and gravitational waves (AGW)
Atmospheric gravitational waves (not to be confused with gravitational waves linked to Einstein's theory of relativity) play an important role in the dynamics of the medium and upper atmosphere.

Propagating through the thermosphere and interacting with ionospheric plasma produce ionospheric disturbances that can interact with the geomagnetic field up to the level of F layer, influencing its ions concentration, gravitational waves propagating from the lower layers, create, in fact, a flux of ions that affect the economy of the ionization process that consists in getting or losing electrons. This influence seems more marked in the formation of the night F2 layer, where gravity waves. would help to provide a small but continuous source of new ionization, contributing to the maintenance of residual night ionization. On the other hand, the effect of gravity waves on the D region is negative since they can increase their absorption especially for the lower frequencies of the HF spectrum and even more so for medium waves. AGW are neutral pressure waves with a high wavelength (with a period T varying from 10 to 180 minute that extend within the thermosphere and the mechanism that generates the wave is an oscillation caused by the displacement of an air cell that is relocated to its initial position due to gravity and the movements that generate it have various kinds, in the low atmosphere they are activated by different meteorological phenomena such as temporal formations, action of winds on the Earth's surface, cyclonic formations and instability' caused by jet stream, while at high latitudes AGW are located more in the upper atmosphere and have causes associated with joule heating, Lorentz forces, and particle precipitation related to the magnetic field and coming from the sun. The different level of insolation between the two hemispheres results in a strong thermal imbalance that generates a wide circulation of currents in the lower ionosphere. In the summer hemisphere, so the warmer an ascensional current is created, compensated by a current in the opposite direction in the cold hemisphere, this is the dynamic that generates the strong ionospheric winds. These oscillations at temperate latitudes occur in the low atmosphere (limits of the troposphere) and consequently

propagate within the Mesopause (about 90 kilometers above sea level), up to the thermosphere, fully involving the E region. Thunderstorm perturbations, lightning, sprites, cyclones, storms and strong weather disturbances, are sources of gravitational waves that create disturbances to the D and E layers, and even to the F region.



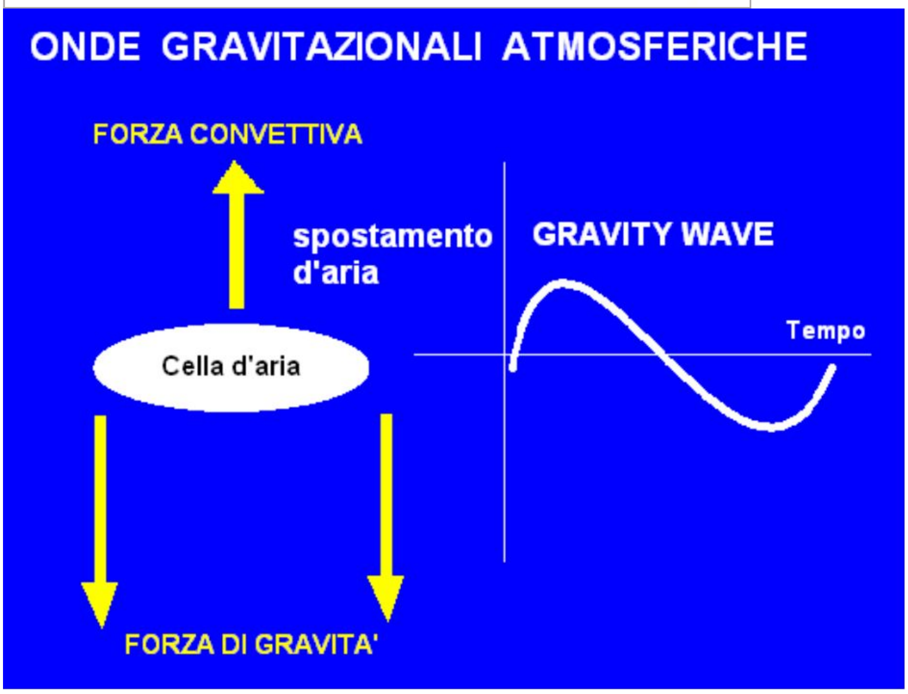


Fig. Atmospheric gravitational waves are an essential element of correlation between the lower layers of the Atmosphere and the Ionosphere that can influence the behavior of the atmosphere and therefore of radio propagation. The figure shows the basic principle, which is the oscillation of an air particle that generates the gravitational wave. It propagates both vertically and horizontally and actively transports energy and momentum from the troposphere to the central and upper atmosphere.

Jet stream

These are large wind currents of western direction that run around the planet at altitudes around 100 kilometers and with speeds that can exceed 100 meters/sec.

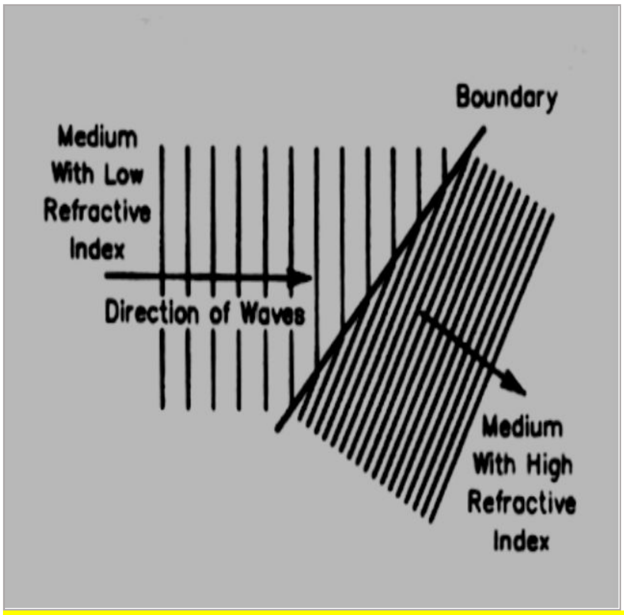
Within each current there are strong turbulences of greater strength and speed that due to friction with the lower layers have repercussions on meteorology, giving rise to areas of high and low pressure. These strong currents occur in the mesosphere which is a very dynamic layer, where winds, atmospheric waves and turbulence, play a particularly important role.

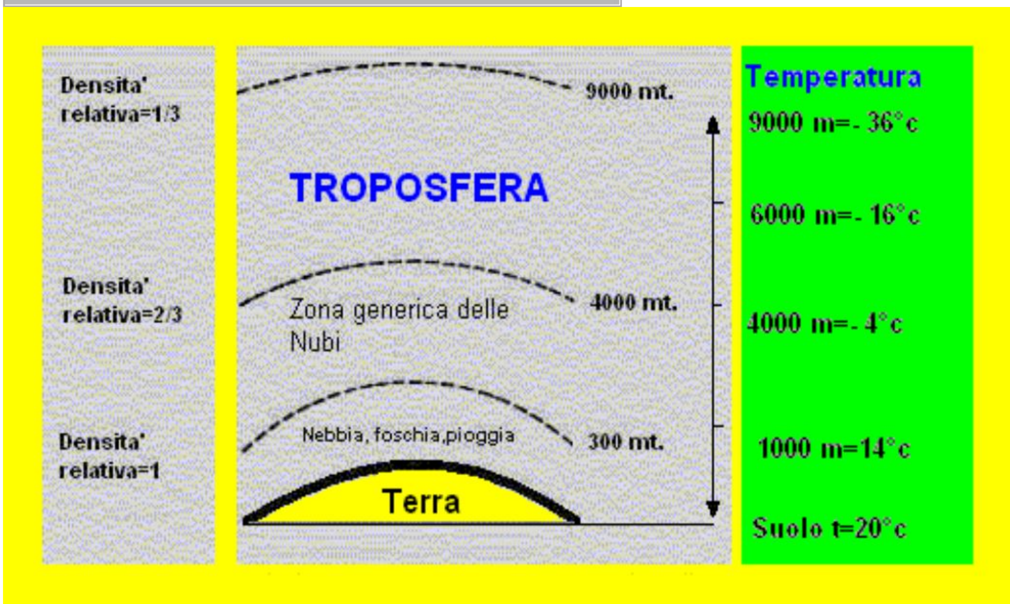
HF propagation

The propagation of HF waves takes place within the Earth's Ionosphere, so the meteorological situation is not the most important element since the reflections of the signals are due to layers that are high (especially for reflections that occur in F region) and therefore distant from the Troposphere that is from the area where the meteorological phenomena develop. However, wave trains propagate from the low atmosphere and many connections occur with the help of region E, and therefore an area that could be significantly affected by the weather situation at the bottom, and the rules of absorption are governed by the molecular situation of layer D, (effects of gravitational waves on the absorption of radio waves) which is the layer closest to the troposphere and therefore most affected.
The effect of gravitational waves, and of the winds present in the stratosphere, have some impact on the quality of HF propagation, it should be borne in mind that at the height of regions D and E (Mesosphere) there are regular and impetuous winds of up to 300 km/h, which could deteriorate the uniformity of the layers. Propagation tends to be better in the presence of large areas of high pressure, not least because the overall absorption situation should be better in the presence of large areas of good weather, but it is difficult to establish and understand what is happening. The behavior of the ionosphere is influenced by ultraviolet solar radiation which is absorbed by the various chemical species present and consequently by the density of free electrons present in the Ionosphere, therefore the solar and geomagnetic situation remains the decisive action that governs radio propagation on the HF frequency. It should also be said that most short-wave QSO take place over large distances, involving states and continents, so the weather conditions can be as varied as possible.

VHF propagation

The situation in this case is reversed, the VHF signals propagate within the Troposphere and therefore the weather situation becomes decisive and governs the propagation of VHF frequencies, from 144 MHz up to 430 Mhz.





It is sufficient to think that the refraction of VHF waves is caused by the variation in the refractive index of the air, caused by the variation in the characteristics of the medium (humidity, air density, pressure, temperature) as shown in the figure below.

The VHF signals that propagate through the troposphere, undergo a deviation especially in the layers within the first kilometers of altitude (3 - 4 Km) since it is in this area that the greatest variations take place, therefore the various propagation phenomena involving propagation in VHF, such as:

-Tropospheric refraction and diffraction.
-Tropo-scatter.
-Tropospheric ducts.
-Temperature reversal.
-Convective cells.

They are a direct consequence of weather conditions.

Sporadic E
The propagation for Es has many points of contact with the weather situation.
The combined action of ionospheric winds and gravitational waves create ion massing around 100 kilometers of altitude due precisely to the propagation Es (Wind Shear theory).
The best condition is that in which an area of low pressure is located between two cold fronts, since these weather conditions should be associated with strong winds and turbulence at the height of
E region, these would be precisely those ionospheric winds that then create the conditions to thicken the ions creating the high-density curtains of free electrons, precisely the cause of refractories for

sporadic E. The more or less intense action of gravitational waves, combined with the presence of other external catalysts such as meteoric ablation and the favorable action of the geomagnetic field, would then determine the intensity of ionization and therefore the ability to send high frequency waves back to the ground, we know that as the frequency used increases, Sporadic E events refractive capacity becomes difficult as the necessary level of ionization becomes critical, this may be due to the difficulty of having all the factors we have just talked about at the same time active. There should also be a correlation between thunderstorms and the formation of the sporadic E layer. Practical observations would seem to confirm this theory, as there has frequently been a significant improvement in propagation conditions immediately after a thunderstorm phenomenon, especially on the high portion of HF. (21-24-28 MHz). The correlations between the lower and higher layers of the Earth's atmosphere would seem to support this hypothesis. The violent agitations within a thunderstorm front, generate gravitational waves that transmit to the ionosphere and this could be linked to the improvement of the propagation conditions triggered by the storm as well as the possible link between thunderstorms and sporadic E. Although it has not yet obtained scientific approval, it is supported by amateur radio operators based on practical observations and statistics. However, official science would tend to exclude this relationship by arguing that the transition zones between the troposphere and the ionosphere, called tropopause and stratopause, thus protect reflective layers from influences on molecular composition and electronic concentration by tropospheric phenomena, as well as They have not found a statistical relationship between the occurrence of ES and thunderstorms. It is also true, however, that on earth there are statistically about 100 thunderstorm electrical discharges every second, with a concentration especially in the equator belt and in the

summer hemisphere (the incidence of ES is higher in the summer months and in the tropical belt), these electric discharges develop an impressive amount of energy, we therefore have a huge level of potential energy that could act as a catalyst for Es, it is certain that not all temporal cells give rise to the formation of Es but a combination of events could take place where electricity could have the function of triggering. A further link with the hypotheses just discussed concerns the discovery made in recent years of an interesting phenomenon associated with normal thunderstorms, these are red sprites. The question is whether and how, this enormous potential energy interacts with the ionosphere and ionization mechanisms, influencing the formation of ES and propagation in general.

Possible sprite-related effects

These phenomena are like lightning that develop in the stratosphere at a height between 10 and 100 kilometers, so electric discharges occur lasting a few tenths of a second that develop due to the difference in potential between the clouds and the high atmosphere.

While at first it was thought that these phenomena were always associated with thunderstorm formations, recent scientific research has shown that sprites can occur even in the absence of thunderstorms, this if on the one hand it makes it even more difficult to interpret this mysterious phenomenon, on the other, it opens up new perspectives on the consequences that these electric discharges can have on the chemical composition and structure of the Earth's Ionosphere and therefore also on the propagation of radio waves , since discharges can reach a height of 100 kilometers and larger events can propagate in a volume of 10000 cubic kilometers, fully involving D layer and E layer of the Ionosphere.

Notes:

Sprite. The discharge propagates from the troposphere to a height of 100 kilometers, directly involving the Ionosphere (region D and region E). The figure on the right shows a daytime average of sprite occurrence in the northern hemisphere summer season. It is estimated that the global occurrence of sprites is about 720 events/day on average, it has also been found that the most active regions are in North and South America, Africa and Southeast Asia.

Absorption

Meteorological effects such as gravitational waves, and stratospheric warming can have a negative impact on radio signal transmissions especially for lower frequency signals (medium waves and low bands of the HF spectrum) as they increase the absorption of D region.

Absorption is caused by collisions of electromagnetic wave electrons with neutral atoms found in D region, and as a result of these collisions electrons yield energy.

Atmospheric gravitational waves tend to thicken ions within D region, thus increasing the probability of collision by increasing energy absorption accordingly. Large-scale observations have increasingly convinced me that absorptions play a decisive role in the propagation of radio waves, in an analysis of propagation conditions and in order to understand whether a given QSO is possible, it is necessary to give great importance to the degree of ionospheric absorption, this is a determining parameter as well as solar and geomagnetic indices.

Solar storms and HF propagation improving

Contrary to what can be expected, geomagnetic storms can favor propagation openings by creating favorable and sometimes exceptional conditions. The frequencies most affected are the lower part of the HF bands up to medium waves. The analysis of various cases shows the certainty that it is something linked to the perturbed conditions of the ionosphere because of intense geomagnetic phenomena.

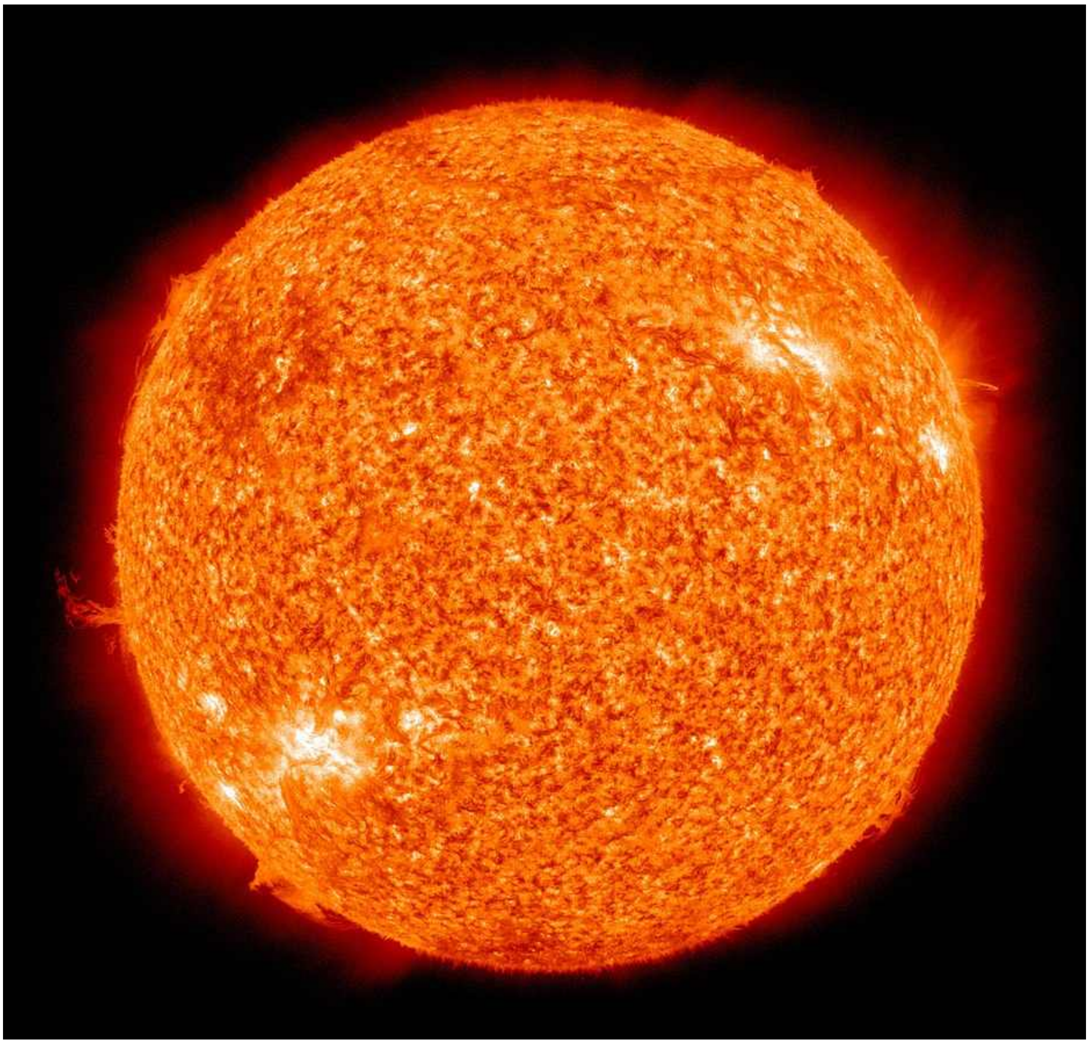


Fig. This is a false-color image of the Sun observed in the extreme ultraviolet region of the spectrum.

(Image NASA- Wikipedia public domain).

Solar Flares

Activity on the sun's surface is evidenced by the density of sunspots, which appear as dark areas on the photosphere, fluctuating in frequency within a cycle of activity approximately eleven years. They are dark regions because they are "colder" than the bottom: their temperature is of the order of 4000°K, while that of the surrounding surface is 6000°K. Intense magnetic fields are located in sunspots and, on the immediately upper part of the atmosphere, intense flares often occur, producing powerful bursts of radio energy at frequencies between about 5 MHz and 300 MHz Often, during the most intense flares, an intense flux of high-energy charged particles (cosmic rays) traveling at a speed of 500-1000 km/s is emitted: when such particles reach the Earth's magnetic field they cause intense radio disturbances and magnetic storms, with aurora formations. The map of solar radiation emissions due to flares appears much wider than that occupied by sunspots. Unlike the radiation from most celestial radio sources, which is un polarized, the radiation associated with solar flares is circular polarization, being caused by the spiral trajectories of the electrons that follow the local, intense, magnetic field associated with the flare. In any case, solar flares give rise to a jet of electromagnetic radiation, which ranges from the HF field to X-rays and gamma rays as well as the expulsion of matter from the solar corona, all this is emitted in interplanetary space and therefore also in the direction of the earth, whose magnetic field captures the plasma that aligns following the lines of force of the Earth's magnetic field, focusing on the poles, near the auroral oval. The explosion of energy that occurs during a blast is enormous, comparable to an atomic explosion of ten billion megatons. By convention solar flares are divided into three classes, C, M and X which depend on the amount of energy flux developed.

Flare classification

1. FLARE CLASS C is the least powerful and does not immediately affect the ionosphere, although the emitted particles may affect the ionosphere several hours later.
2. FLARE CLASS M is a medium-energy flare and is enough to affect the Earth's ionosphere immediately after the event, but also to produce delayed effects of solar radiation.
3. FLARE CLASS X are the most powerful and destructive and can cause severe geomagnetic storms and long communications blackouts.

The electromagnetic radiation of an active Flare, ultraviolet rays, X-rays, visible light and radio spectrum, travel at the speed of light and reach the earth with a delay of about eight minutes, so that the effects on the ionosphere can begin while the Flare is visually observed. Radio communications can be immediately affected after the Flare, or the effects can be felt one to two days after the start of the Flare, however, for a limited period and immediately after the phenomenon, there may be conditions that favor propagation. The increased intensity of the solar wind caused by the Flare can agitate the ionospheric plasma, breaking the uniformity of the layers, changing the geometric shape of the ionosphere and its volume.

SIGNIFICANT EVENTS

Below are some of the most significant geomagnetic events that I have recorded and that have generated some excellent openings:

- Event of 20.11.2002 index Kp=7
- Event of 28.10.2003 index Kp=7
- Event of 04.11.2003 index Kp=7
- Event of 03.01.2005 index Kp=5
- Event of 07.09.2005 index Kp=8

Solar radiation pressure

Due to solar radiation pressure, the ionosphere and the earth are not two concentric spheres. This leads to a

continuous deformation of the Ionosphere which is noticeable when the sun sets on a meridian (terminator). Signals passing through the ionosphere for thousands of kilometers may therefore meet oblique surfaces with respect to the ground (tilt), as well as curved surfaces that can give focusing effects. This phenomenon is even more exacerbated in the presence of heavy solar emissions, as is the case with the most intense solar disturbances. In this case, due to the solar wind that increases in intensity, the magnetic force lines, compressed on the illuminated hemisphere, stretch to "comet tail" moving away from the opposite hemisphere.

Theoretical hypotheses

Given the uncertain nature of ionospheric propagation, it is not possible to identify with certainty the elements that support it. One thing, however, is certain and derives from years of research and listening to radio frequencies: the classic model of propagation for ionospheric jumps is no longer able to explain the phenomena that regulate and support propagation. I am increasingly convinced that we will have to look for something different from this classic model which has in some respects proved to be outdated. Therefore, I have tried to formulate some plausible hypotheses that could explain why these extraordinary openings can occur. One thing is almost certain is that due to the solar wind the geometry of the ionosphere is altered. The ionosphere undergoes a compression on the sunlit side and a progressive elongation on the opposite side, until in the most extreme cases to confuse with the tail of the magnetosphere. (Figure below). I think this geometric variation may prove favorable for signal propagation. The routes affected are those in darkness, side not directly affected by the flux of energy from the sun. An extreme explanation leads me to look beyond the Earth's ionosphere, inside the magnetosphere plasma, and into the tail of the magnetosphere, where because of the recombination of

electric charges, there could be points of reflection or better than waveguides in the magnetosphere on the dark side of the earth. Guides useful for conducting HF signals can be 60,000 kilometers long, or a little longer. The round-trip distance of the signal could also justify the delay of the signal that I have repeatedly detected during the most intense geomagnetic events. Very often, the path of the signal does not strictly follow the line that connects the two geodesic points but follows the strong distortions of the magnetic field and of the ducts in the magnetosphere. This is a fascinating hypothesis but at the same time difficult to prove. It is clear, however, as observed in all the analyzed events that the "propagation window" is short (a few hours) as subsequent, energy recombination increases the density of D region and then blocks propagation.

Resonant cavity

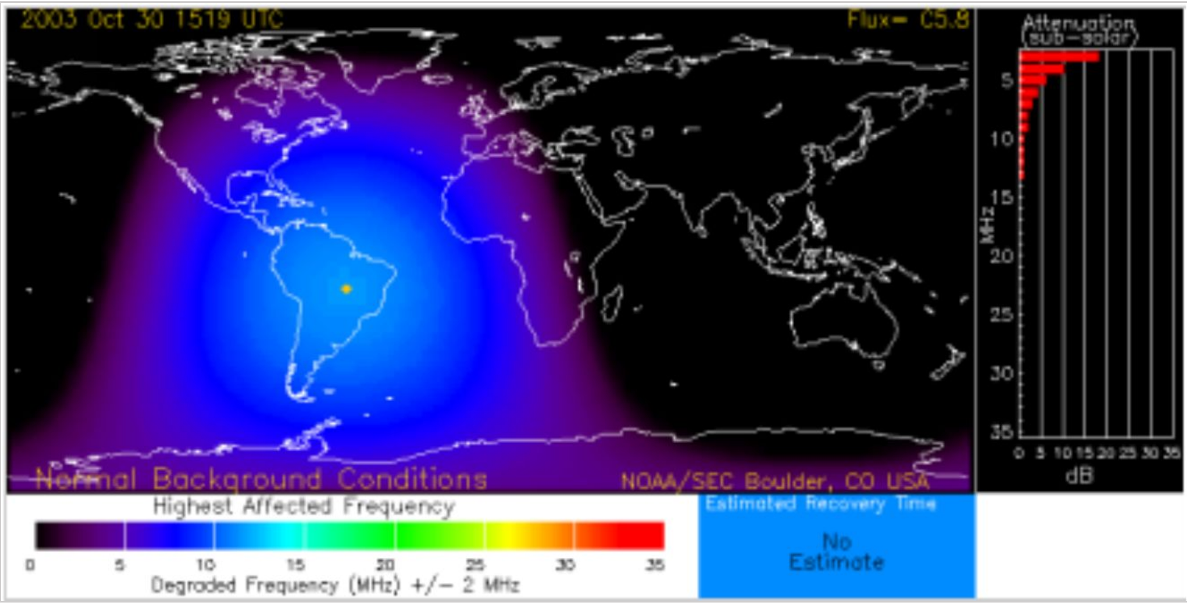
The impression is that during some very intense geomagnetic events on the dark side of the Earth, a large resonant cavity is formed that extends to the limits of the magnetosphere. Proof of this is the signal characterized by an obvious rumble or echo. Propagation within this huge cavity could occur with very low losses.

HF propagation blackout of October 30, 2003.

Introduction

The strong solar activity that began on October 28 and caused by a large set of spots, has progressively degraded the propagation in the HF bands, up to a total blackout on 30/10/2003, because of two large flares (X.17.2) and (X.10), among the most intense in recent years. Spot 486 turns out to be the largest complex in this solar cycle.

HF band observation



Listening to HF bands revealed a blackout propagation on all high bands, in the afternoon of 30/10/03 to 15:00 UTC. The propagation was closed from 30 meters and above, with good short skip propagation in 40 meters. While the upper frequencies always stay closed, no beacon was audible from 14 MHz to 30 MHz, propagation closed at 360 degrees, even propagation condition in 40 meters, gradually deteriorated. At 19:00 UTC, the band was incredibly quiet, only few and weak signals were present and subject to flutter fading (Aurora level=10 and Kp index=8). At 21:00 UTC, this was the situation: Completely closed band, with extremely poor propagation also in 80 meters. At 22:00 UTC, only a few weak signals from Spain and closed band (Aurora level=10 and Kp index=8), with slight flutter fading. 22.30 UTC, almost closed band, weak

worthy heard by Germany, Poland, Romania, Lithuania, Spain and Italy zone 5, subject to slight Flutter fading, accentuated on signals coming from Germany.

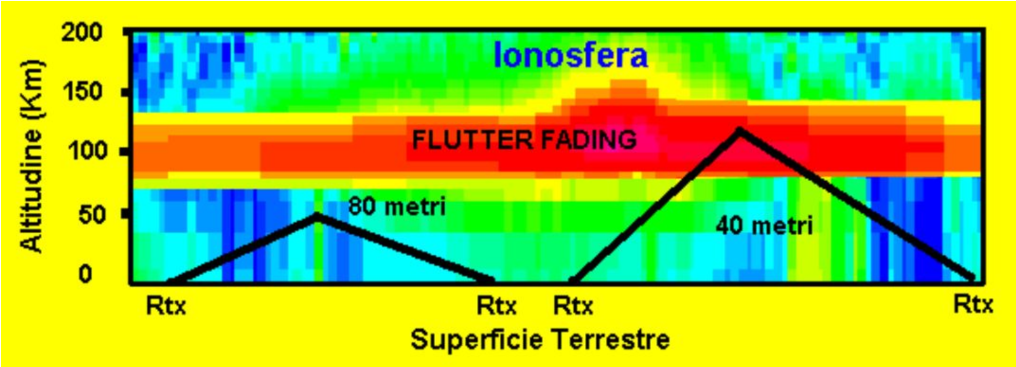


Fig. situation in D region at 15:19 UTC on 30/10/03, the absorption induced by the solar wind is very high. (The intensity of the solar wind has reached values even above 1000 km/sec.). Image: NOAA Space weather prediction center.

Flutter Fading on 40 meters.

A notable phenomenon concerns the Flutter fading of night signals over 40 meters, which I have encountered other times when the magnetic field is very disturbed, the waves of 80 meters do not undergo distorting fading. Especially in the presence of ionospheric perturbations, patches of different electronic density can form, patches a width of a few kilometers, which cause not only homogeneous levels of absorption but also strong instability and evanescence of signals, it is the cause of flutter fading. I noticed that only 40 meters signals are subject to this phenomenon.

A plausible explanation is due to the height where the formation of these irregular patches takes place, which, as is the case with the aurora, are located at altitudes around 100 kilometers above altitude.

The waves of 40 meters at night reach these heights and, in this area, they can also undergo reflection, vice versa, longer waves like the 80 meters fail to penetrate the layers up to these heights, since they are already reflected at lower altitudes.

SOLAR FLARES X.17.2 of 28/10/2003 and X.10 of 29/10/2003

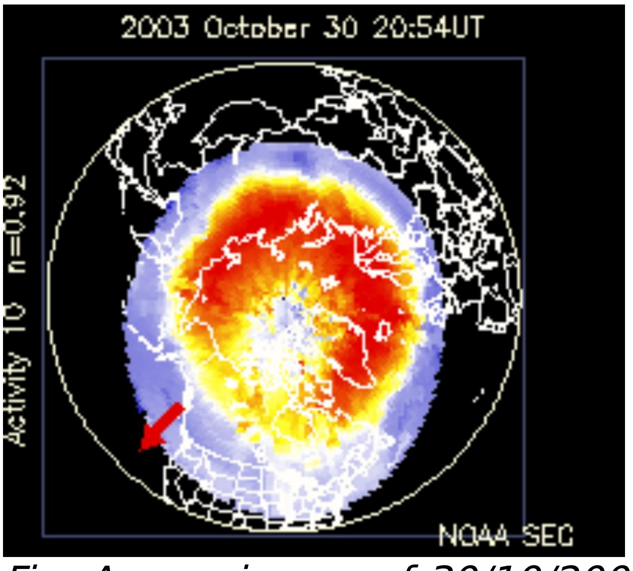
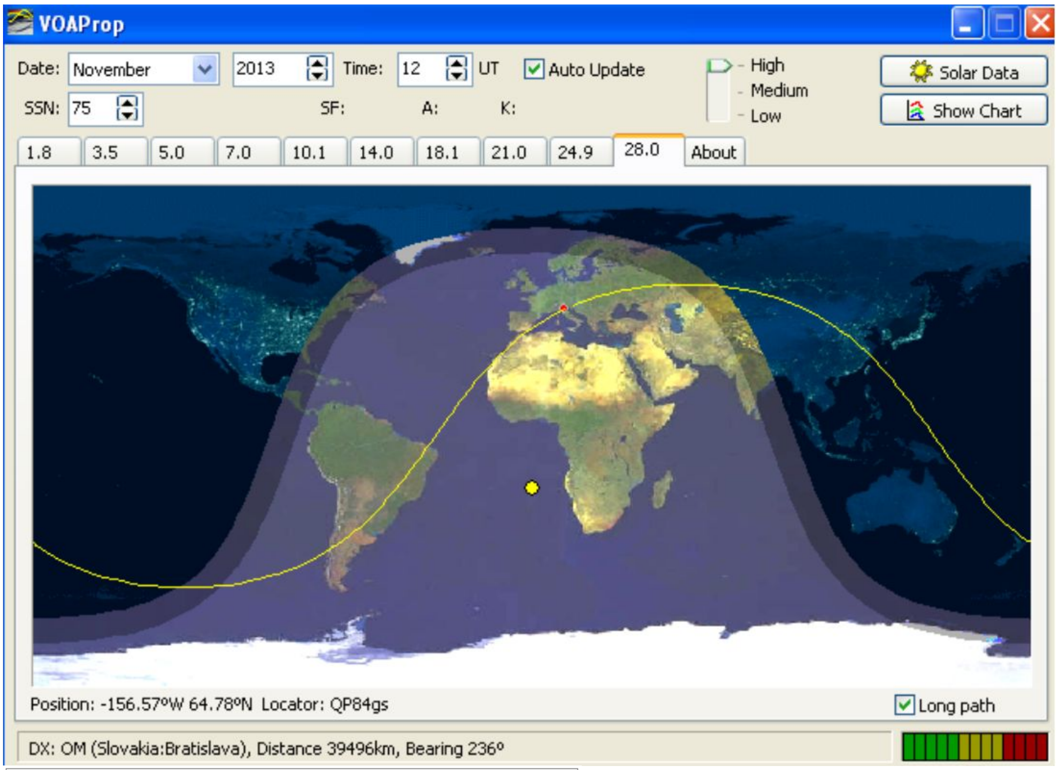


Fig. Aurora image of 30/10/2003 with level of 10 at 20.:54 UTC. Maximum level of aurora. Image: NOAA Space weather prediction center.

Study of the Long Path Echoes

Introduction

This document reports some experiments in receiving echoes in the high band of HF, due to multiple reception of long path propagation. In the presence of adequate propagation conditions, it may happen that the signal is received both for the short path and for the long path. In this case it is multipath that generates a noticeable echo effect on the signal. Let us try to formulate some hypotheses taking into account, however, that talking about long path, if the signal starts from a very directive antenna, after having traveled the direct short path can continue in the same direction thus completing a turn of the earth equal to about 40000 km if at ground level, something more if at the ionospheric higher level. But if the signal starts from a dipole, or a little antenna, it could make a shorter path while circling the earth but not on a plane centered in the center of the Earth. The lines of force of geomagnetic field, undoubtedly have an enormous influence on this. So, starting from the analysis of the various cases we try to understand something more about the propagation of radio waves in HF. The time a radio wave takes to circle the Earth's circumference is: 40,021/299792.458 = 0.1335 sec. In fact, we will have to expect 138 ms, considering an additional 1400 km length of the path due to the reflections between the earth and the ionosphere (if we refer to the classic model). This is also the classic delay time (dt) provided in the official propagation texts for long path propagation for the great circle.



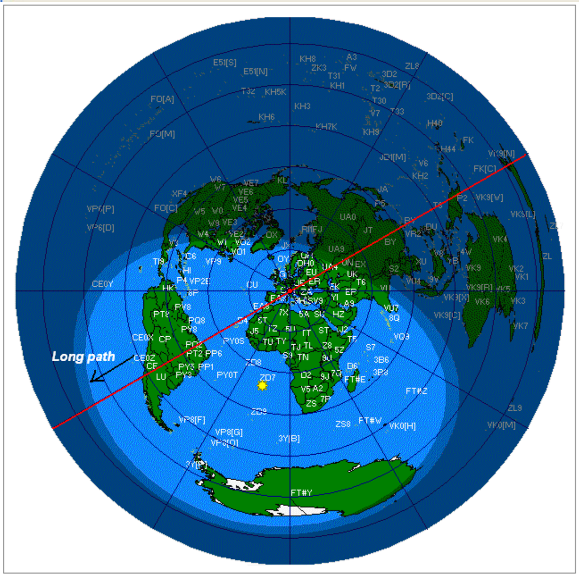


Fig. Long path centered with OM3PA referring to case 1, traced with the VOAProp program of G4ILO Azimuth map on the right. Signal path analysis: In case the signal follows the great circle, it should travel about halfway on the illuminated side of the globe and the other half on the

dark side. Without lapping the Auroral areas (near the poles). Map made with Dx Atlas software.

The cases analyzed

Let us see below the analysis of some cases:

1. 1-CW reception of OM3PA by IK2GRA with long path echo dt=125 ms on 10.11.2013 (SFU 148- KP=3)
2. 2-Reception of its signal in CW by IK2GRA ECO dt=139 ms on 16.11.2013 (SFU 178- KP=3)
3. 3-Reception of its signal in CW by IK2GRA ECO dt=140 ms on 22.12.2013 (SFU 144- KP=1)
4. 4-CW reception of YU5D by IK2GRA with long path echo = 130 ms. on 22.12.2013 (SFU 144- KP=1)
5. 5-CW reception of UN9GD by IK2GRA with echo long path=140 ms. on 22.12.2013 (LPP long path continuation) (SFU 144- KP=1)

An important outlook

From the analyses we have done, a complete lap of the earth is carried out in 140 ms.
It is a fact, and it is not distorted by delays in the signal chain. If the signal could travel at zero altitude it would take 133 ms, so we know that the path (considering negligible any small slowdown in the ionosphere) is 40000x140/133=42105 km, that is, 5% more. If it were to travel linearly, it would have to make a circle at an altitude of 6370x0.05=318 km. Or lower but not linearly. What matters is this 140ms and that 5%. The elongation mechanism is not known to us precisely, but it always seems to be there, in the order of 5%. (5% rule). We can make some hypotheses: the altitude where the signal travels are variable and may depend on the condition of the ionosphere on that day, moreover the signal runs along the ionospheric duct continuing for jumps.
Another factor that could affect the lengthening of the path is anomalies in the Earth's magnetic field.

Analysis of some case studies

Let us see below the analysis of some significant cases conducted with Audacity and some comments:

<u>**Case 1**: Date 10.11.2013 12 UTC 28 Mhz. SFU 148 Kp=3 (quiet) IK2GRA receives OM3PA with a dt=125 ms</u>.
The long path in this case is 39317 Km. A theoretical dt LP of 131 ms is expected, which with the 5% rule should be 137.5 ms. We measured 125 ms. The OM3PA signal has made a shorter path, different from the great circle. This is an anomaly that we are not able to explain in this moment. The graph with the audio analysis of the signal below requires a brief explanation: the signal part on the left is a CW line 150 ms long. Because the delay is 125 ms. The echo signal, on the right, about half wide, partially overlaps with the main signal. The other charts are also to be read in the same way. As for the time scale in the horizontal axis, each marking corresponds to 10 ms.

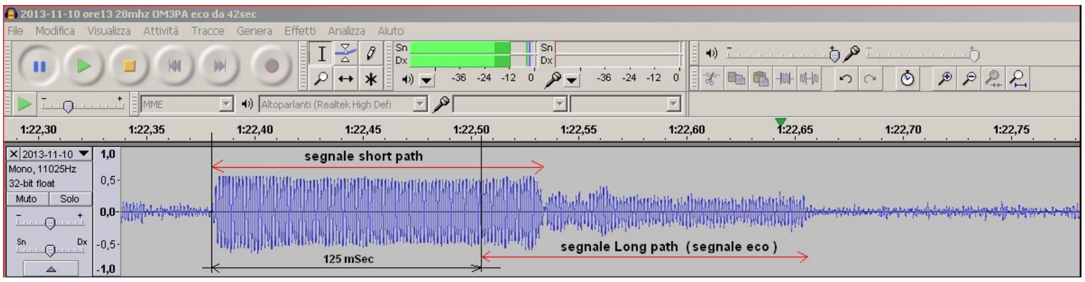


Fig. Audio analysis of case 1. Recording of OM3PA audio signal made by Annibale, IK2GRA. You can see the temporary overlap of the echo with the main signal (the largest signal) as the delay of 125 ms. is less than the duration of the CW line. Note the difference in signal amplitude LP, about half that of the SP signal, confirming the low attenuation in play in this propagation mechanism. Credits: IK2GRA.

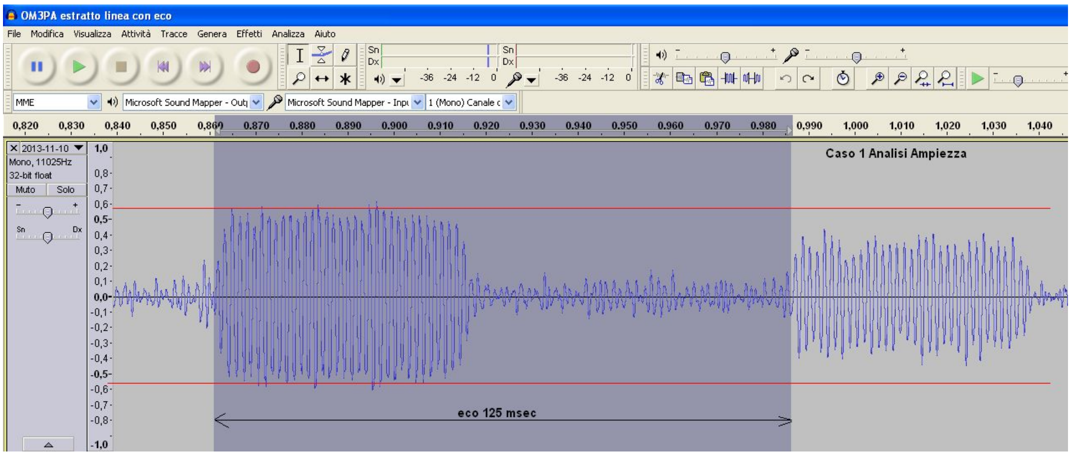


Fig. Always case analysis 1: Receipt of OM3PA by IK2GRA. In this case you can see the delay of 125 ms, the echo signal compared to the main signal and you can see how the difference in amplitude between the short path signal and the long path signal is minimal. The signal travels inside the LP duct with incredibly low attenuation. Credits: IK2GRA.

<u>Case 2:</u> <u>16.11.2013 at 10.07 UTC - 28 Mhz. SFU 178 Kp=1 (quiet) IK2GRA receives its echo with a dt=139 ms.</u> In this case the dt is consistent with the theoretical 138 ms of an LP signal. 90W transmitted power with vertical multiband antenna. By decreasing the power < by 50 w, the echo disappeared. The phenomenon lasted about 45 minutes, with varying intensity.

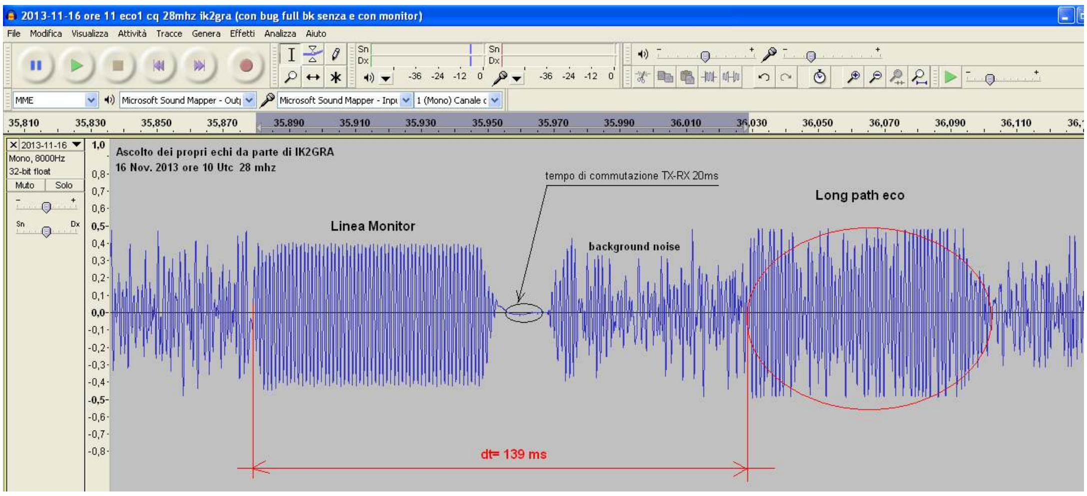


Fig. Case Audio Analysis 2. Signal recording of one's signal made by Annibale, IK2GRA. Also, in this case, we see the temporary overlap of the echo with the recording of the transmitted line and the moment of null due to the switching time of the transceiver in the transition from TX to RX. The dt of the measured LP echo is 139 ms. (We subtracted the 10 ms of error due to the eco= dt-error transceiver.) The signal was transmitted with a power of 90W with multiband vertical antenna. Decreasing the power below 50 w, the echo disappeared. The phenomenon lasted about 45 minutes, with varying intensity. Credits: IK2GRA.

Case 3: 22.12.2013 at 11.15 UTC - 28 Mhz. SFU 144 Kp=1 (quiet) IK2GRA receives its echo with a dt=140 ms. Again, the measured dt long path is consistent with the theoretical value of 138 ms.

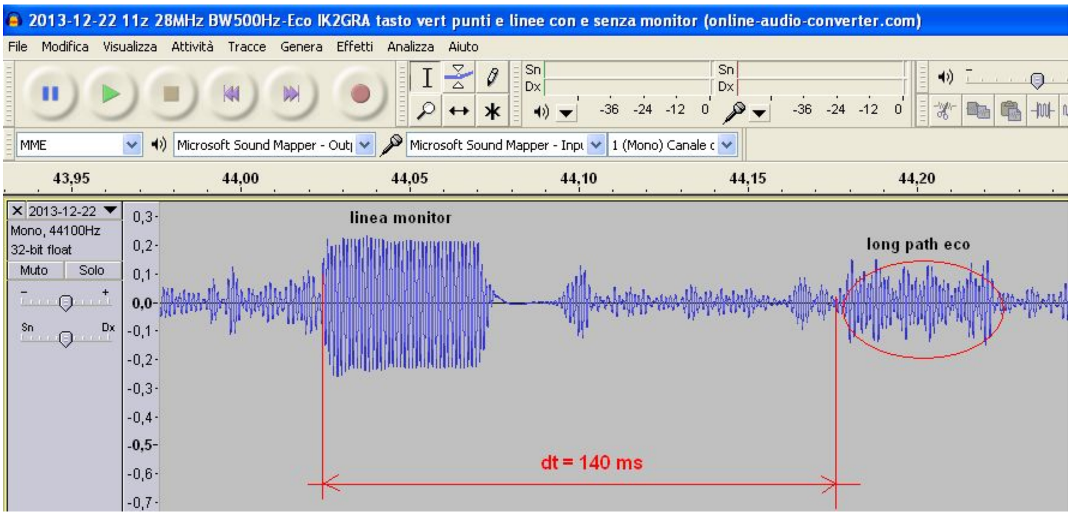


Fig. Audio analysis of case 3. Recording of his own signal made by Annibale on 22.12.2013. The dt of the measured LP echo turns out to be 140 ms. (Again, we subtracted the 10 ms of error due to the eco= dt-error transceiver.) Credits: IK2GRA

Case 4: .data 22.12.2013 11.00 UTC - 28 Mhz. SFU 144 Kp=1 (quiet) Receipt CW of YU5D by IK2GRA with eco long path = 130 ms. In this case, the same considerations were made in case 1 of OM3PA. Here, we are faced with a

lower dt than might be expected for an LP propagation that follows the great circle.

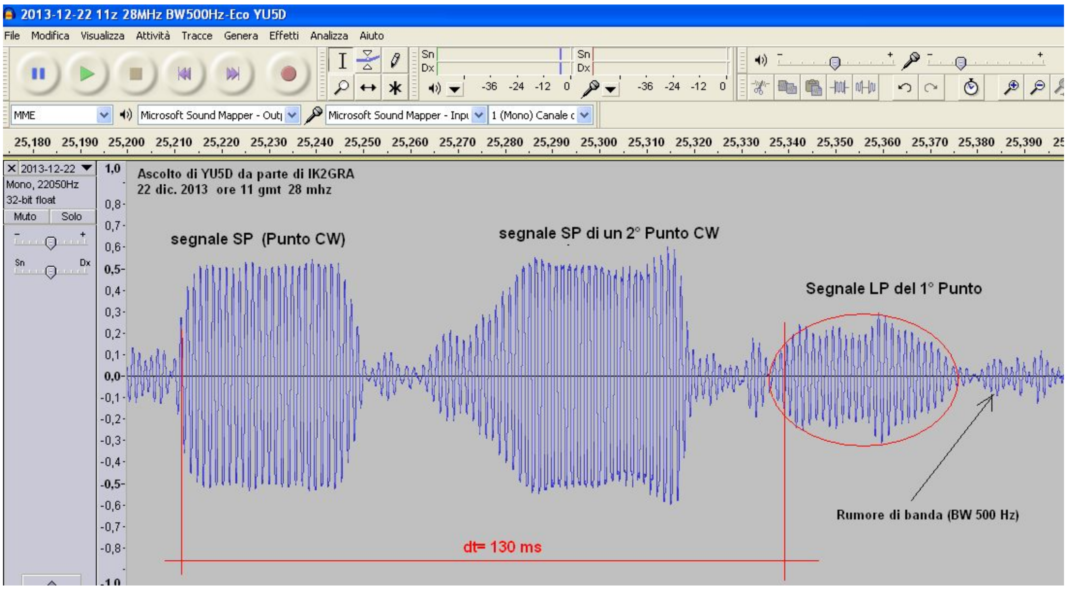


Fig. Case analysis 4. IK2GRA received YU5D. The dt is 130 ms. The same as in the case of OM3PA. It is therefore a reception that devises by about 7ms. from 137 ms (131+5%) that we will have to have respect for YU5D's LP for the great circle. Again, we are faced with a very low attenuation of the echo signal (about 3 dB) as the amplitude of the LP echo signal is half that of the SP signal.

Let us take a closer look at one of the most significant cases, with a possible double turn of the earth.
This is the receipt of YU5D by IK2GRA.

<u>**Description:** .data 22.12.2013 at 11.00 UTC - 28 Mhz. SFU 144 Kp=1 (quiet) Receipt CW of YU5D by IK2GRA with long path echo = 130 ms.</u> In this case, the same considerations were made in case 1 of OM3PA. Here, we are faced with a lower dt than might be expected for an LP propagation that follows the great circle.

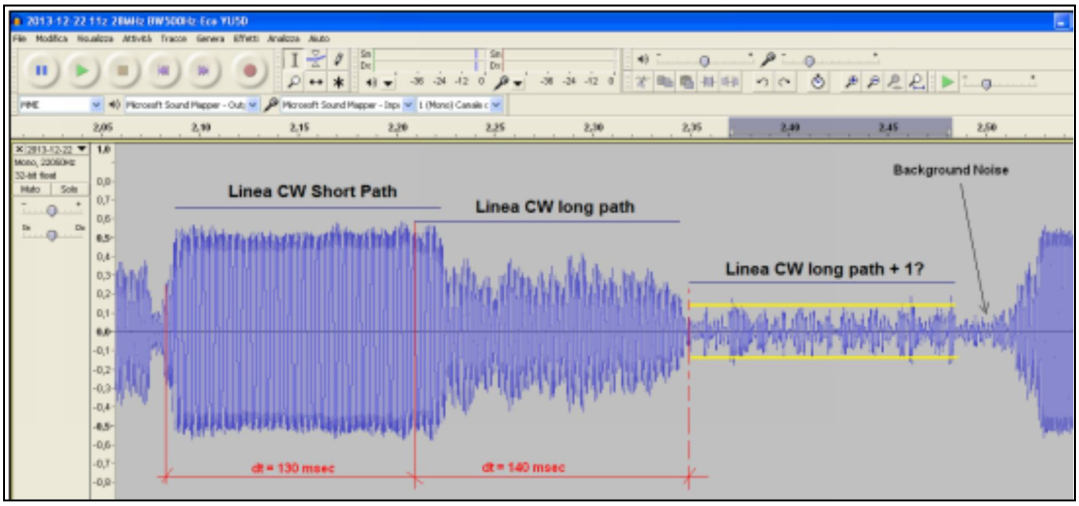
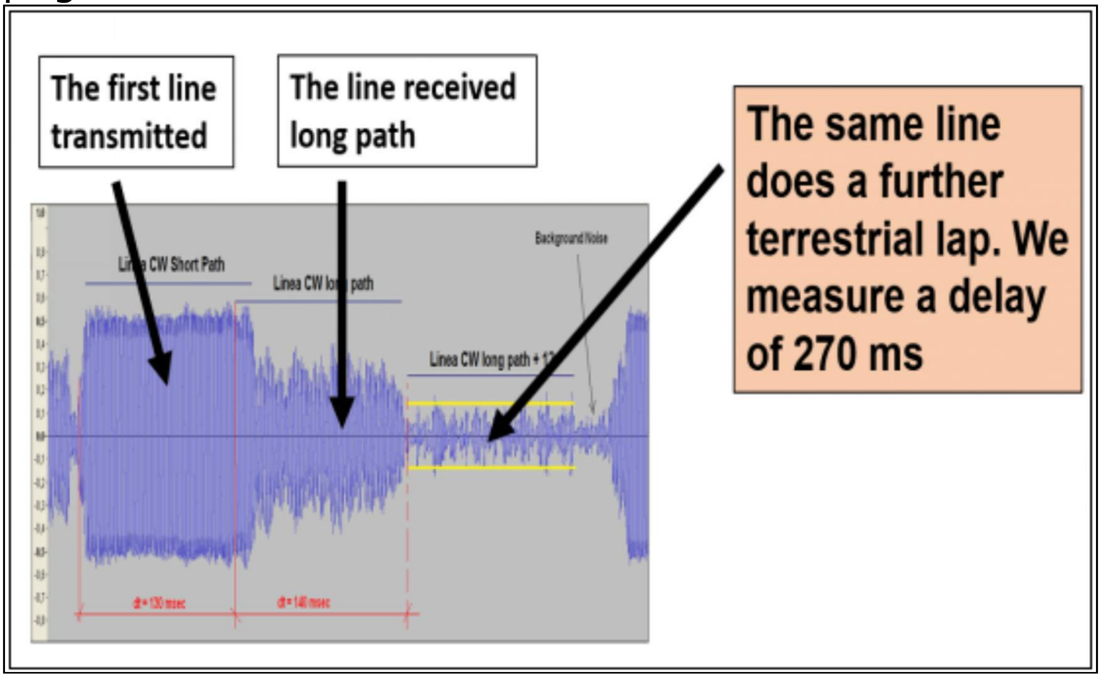


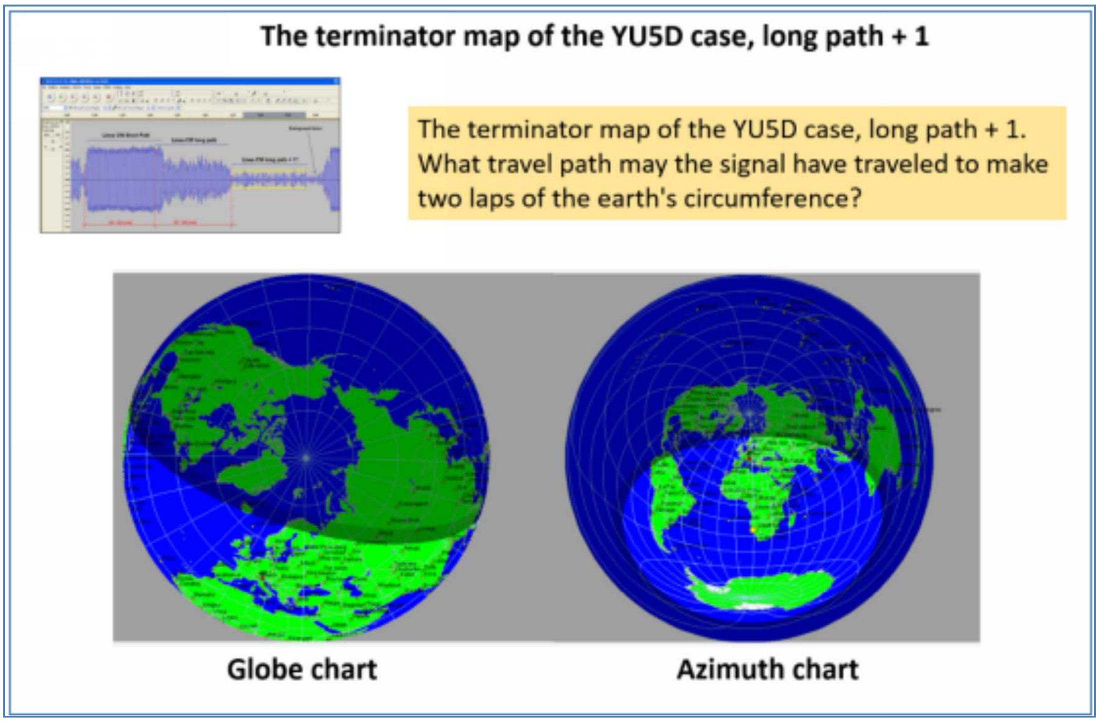
Fig. IK2GRA received YU5D. In this case the dt is 130 ms. It is therefore a reception that devises about 7 ms from 137 ms. (131+5%) that we will have to have compared to the YU5D LP for the great circle. Again, we are faced with a very low attenuation of the echo signal (about 3 dB) as the amplitude of the LP echo signal is half that of the SP signal. The figure in fact shows a portion of the YU5D trace, where you can see well the low attenuation of the path compared to the short path signal (about 3 dB). This recording also shows another important detail: in all probability you also see a part of the CW line confused between the background noise that I called LP+1 that is, an additional lap of the earth. Each timescale marking in the horizon axis is 10 ms.

Some notes about receiving YU5D

The LP signal of YU5D is strong, compared to the SP signal, because it has an attenuation of only 3 dB. Let us try to speculate and analyze the audio track in detail. In theory it is possible that the YU5D signal could take a subsequent turn inside the ionospheric duct, in this case I should find an echo signal that we could call LP+1 about 140 ms. from the main signal SP. You should expect an attenuation of another 3 dB and then I should find the LP+1 signal confused in the background noise. In fact, a portion of the undecodable signal appears to be present, as shown in Figure. Similar considerations can also be

made on the UA3KW signal, always highlighted in the next page.





Map created using the DX Atlas software, www.dxatlas.com.

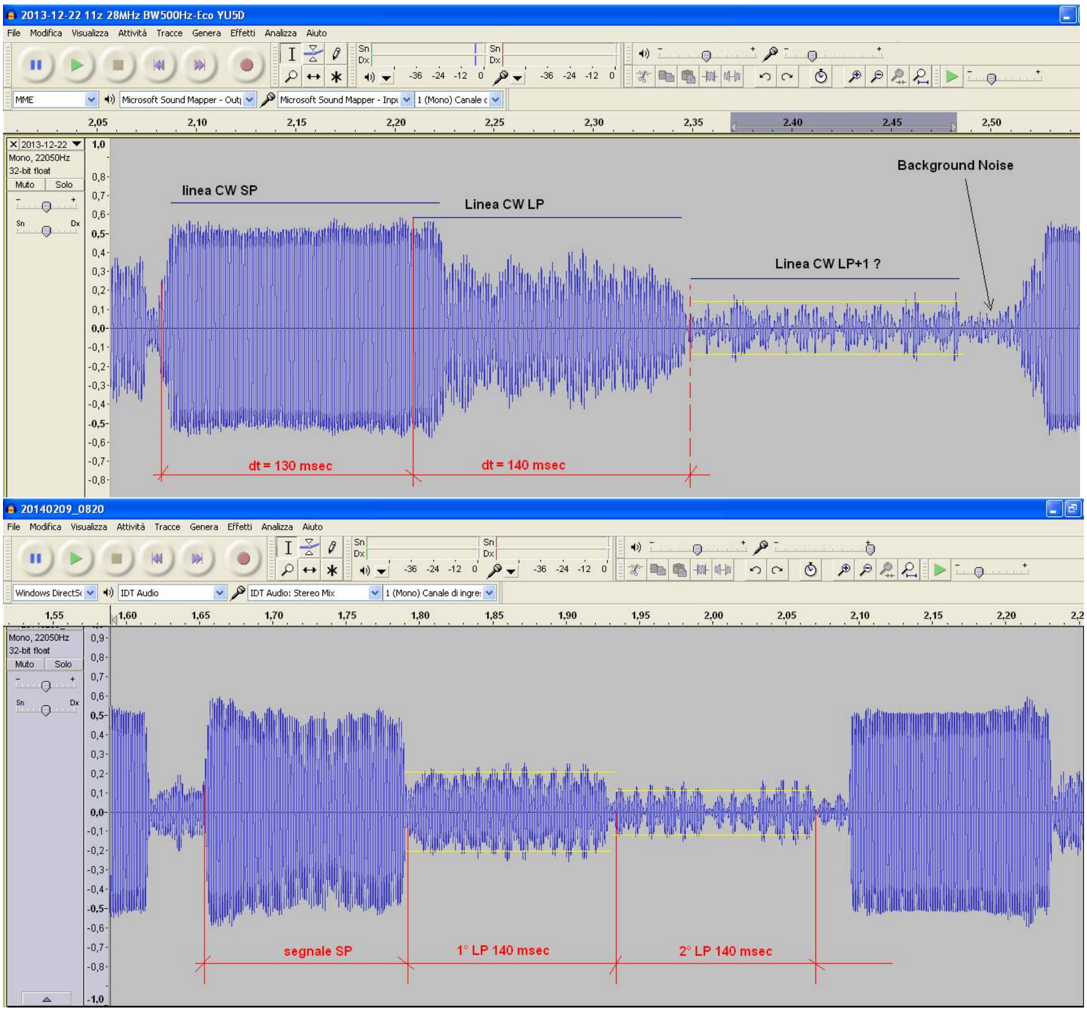


Fig. The figure shows two distinct recordings, the first track at the top is YU5D, where you can see well the low attenuation of the route compared to the signal SP (about 3 dB). The recording below is related to another case of double long path on the UA3KW signal.

<u>**case 5**: date 22.12.2013 11 UTC - 28 Mhz. SFU 144 Kp=1 CW reception of UN9GD by IK2GRA with echo long path=140 ms</u>

In this case we will have to be faced with a case of LPP (4) (long path to continue), measured with a dt =140 ms. The UN9GD signal after being received by IK2GRA continued and traveled a further round of the earth. This hypothesis is also reinforced by the fact that UN9GD transmits with a Quad 4 element antenna, therefore strongly directive and with a good F/B. This case is also

interesting because it has an anomaly on the echo signal, which we will talk about in more detail later.

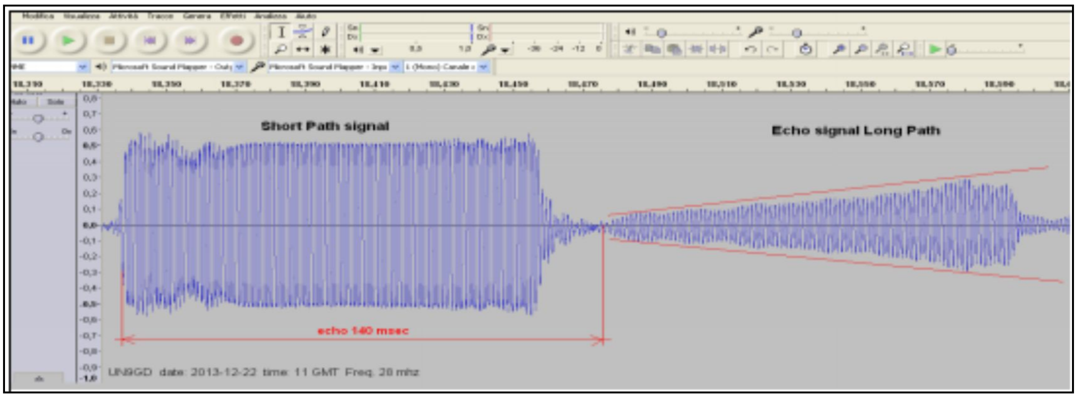


Fig. UN9GD signal where you can see the conical echo.

Some Tests in SSB

During the ARRL 10 meters contest in December 2013, I also conducted some experiments in SSB, recording several long path echoes. In this case there are technical difficulties to analyze the signal as the delay times are not such as to easily discriminate the echo component from the main signal. The Eco signal overlaps the main signal trace. Attempts to highlight echo are shown in the figures below. Although with objective difficulties in discriminating the echo from the main signal, the measurement appears to be around 130 ms, but given the criticality of the measurement it is not possible to make further considerations and the tests in SSB are not considered reliable.

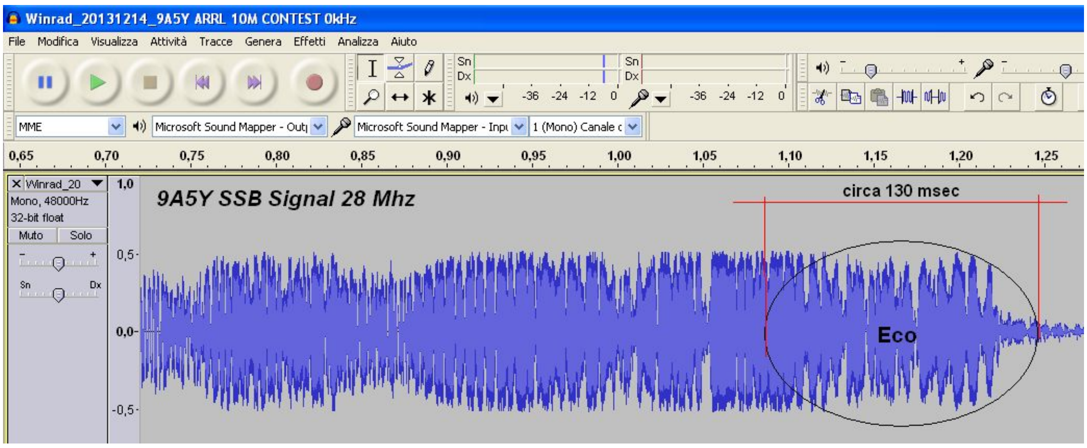


Fig. Analysis of a signal portion of 9A5Y in 28 MHz SSB recorded during the ARRL 10 meters contest 2013. The signal was recognizable as it had a strong echo. (9A5Y date received 14.12.2013 at 12:21 UTC by IK3XTV.

Analysis with VOACAP ONLINE

Voacap is a program for predicting and studying propagation created by Jari Perkiömäki OH6BG, and available online at: http://www.voacap.com. Using this software, we tried to make simulations with the real data of some of the cases analyzed. The program confirms the possibility of long path openings consistent with those detected and connected to the peak of the MUF (see note 3).

Descriptive example in the following figures:

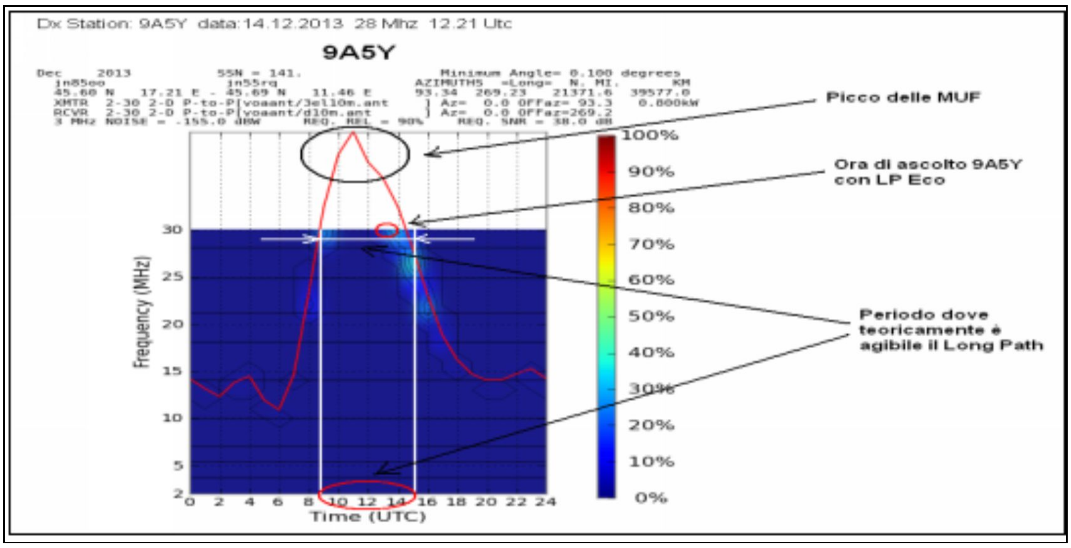


Fig. Example of path and MUF analysis always performed with VOACAP and referred to listening to 9A5Y. (MUF Voacap see Note 3)

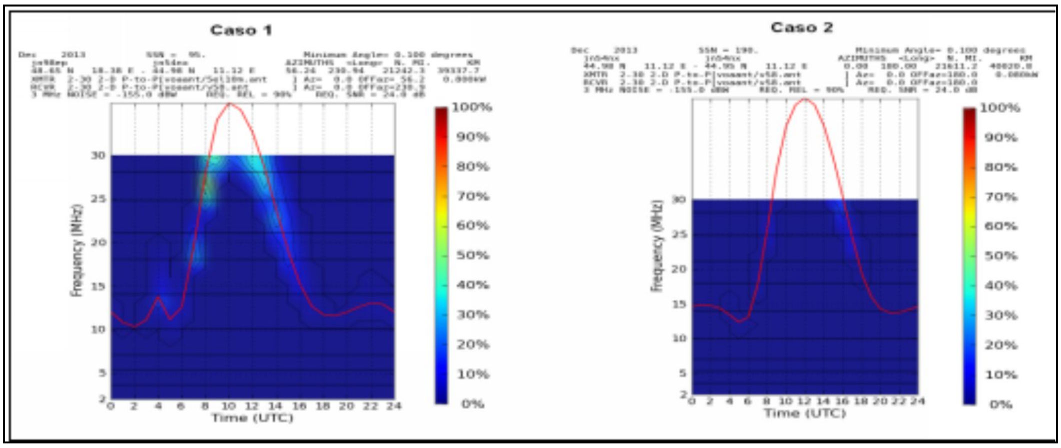


Fig. Analysis of the MUF and the theoretical feasibility of the long path connection with the VOACAP online program. Case 1 and case 2 were analyzed with the forecasting software that confirms the long path times and highlights the opening of the LP path near the maximum peak of the MUF (3), which go up right around the times of the recording of the echoes.

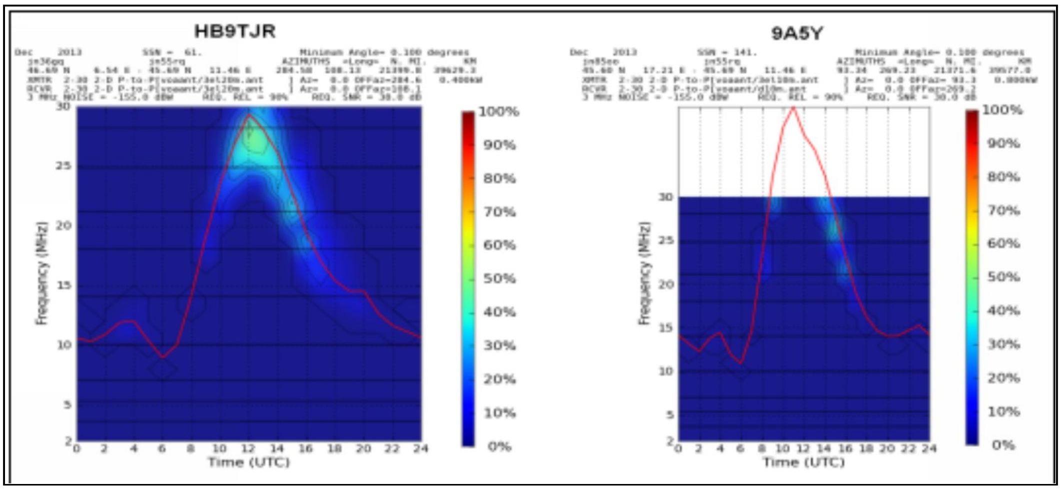


Fig. Analysis of the MUF and the theoretical feasibility of the long path connection with the VOACAP program of HB9TJR and 9A5Y, with the forecasting software that confirms the long path times and highlights the opening of the LP path near the maximum peak of the MUF (3), which reach the peak right around the times of the recording of the echoes (Red curve).

What allows the signal to exit the wave guide?

That is the important question to which we are trying to give a coherent answer. The signal travels inside this wave guide, with a mechanism like whispering gallery (1) and I can think of the analogy with fiber optics, so I think of something like that. But because the ionosphere is not a closed optical fiber but has a series of discontinuities, it is these discontinuities that let the signal in and out. I think in the area around the short path the ionosphere allows you to get in and out of duct.

Ionospheric Doppler

The Long path signal can also be affected by mini-dopplers. We tried to analyze the signal with WINRAD to visualize the spectrum. The echoed OM3PA signal is characterized by a mini-doppler with track enlargement. It should be ionospheric doppler, but let us see what it is. The ionosphere is not a static medium, but is an evolving plasma, subject to movements caused by ionospheric winds. The ionospheric layers have vertical and horizontal movements with the consequence that the ionosphere undergoes continuous undulation that changes the reflection point of the signal generating a doppler shift. The long path signal would therefore suggest an ionospheric doppler due to all the irregularities and undulations met by the signal in such a long path, within the ionospheric vault (always referring to the whispering gallery hypothesis). In a moving reflective plane with speed V, a radio frequency signal f is reflected with frequency **reflected f = f ± Δf**. Where the sign ± the direction of movement of the reflective layer.

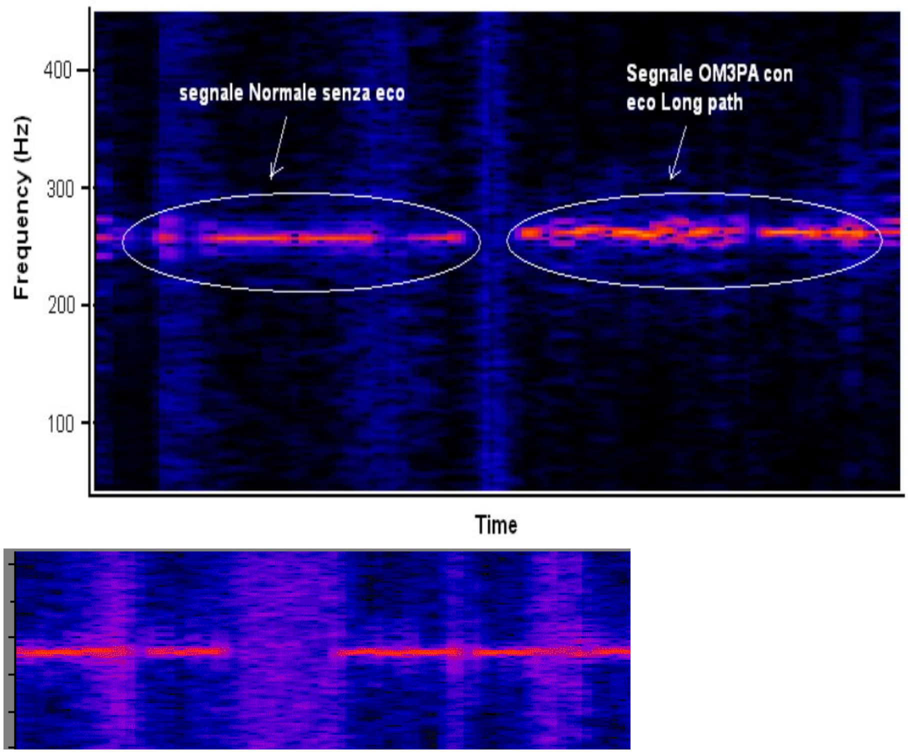


Fig. The image on the right shows the analysis oftheOM3PA signal showing an ionospheric doppler with trace enlargement. The image on the left shows a magnification of the track to highlight in detail the effects of the doppler. The analysis is elaborated with Winrad Software.

Earth's magnetic field

The ionospheric ducts where the signals enter, could be partially diverted by the conformation of the Earth's magnetic field which is not uniform and has significant variations in both intensity and direction. In addition, significant crustal anomalies are also documented. This could be an additional reason for the route elongation detected on long path signals, where we measured 140 ms.

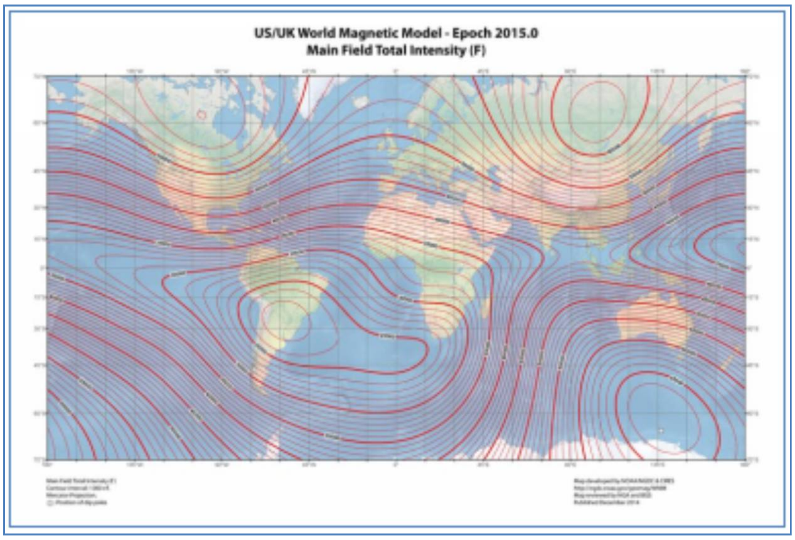


Fig. The Earth's magnetic field is not uniform and has significant variations in both intensity and direction. In addition, significant crustal anomalies are also documented. (Image credits: Wikipedia. Public domain).

Seasonality

A first analysis of the phenomenon shows an Autumn-Winter seasonality (Northern Hemisphere) with an emphasis on the phenomenon in the period from the end

of Autumn until the beginning of winter. The reason is not clear to us, it centers the difference in ionospheric electronic density between the two hemispheres, but the mechanisms are to be clarified. All the cases analyzed have a KP geomagnetic index, never exceeding 3 (quiet geomagnetic field).

Discussion

From the data we have so far, the signals do not always run through the great circle, but they can make different paths, even significantly longer. Here we can only make assumptions, based on the case study that we have available. Propagation could take place as within a wave guide. These wave guides are independent of the wavelength of the signal. Following the classic model of propagation for ionospheric jumps and assuming a jump of 2500 km, it would take at least 16 jumps to complete the entire route. This mean enormous attenuation, but this is not reflected by comparing the amplitudes of the main signal with the echo signal, of the cases analyzed. For the cases we studied, the geomagnetic field was quiet. In addition, the direction of these ionospheric wave guides or ducts may be affected by lines of the Earth's magnetic field that are not uniform but have anomalies. It is quite clear from this analysis that we have this long path-related echo effect, when the MUF reach their peak (Red Gaussian Curve in Voacap forecast tables), and then gradually disappear when the MUF begin to decrease. Thus, the phenomenon has a limited duration and governed by the Gaussian curve of the MUF. We have received and analyzed echoes in both 21 MHz and 28 MHz bands.

Accuracy of measurements:

In the case of the measurements made on the car echoes heard by IK2GRA, we considered a 10 ms error due to the delay times introduced by the electronics of the transceiver in the emission of the monitor signal. So, on

the cases of self-listened signal emitted by the Transceiver we subtracted the delay introduced by the intermediate stages of the transceiver and then made a correction on the measurements with Audacity. We therefore believe that the various measurements of echoes may have a tolerance of between +/- 1 ms. The TX-RX switching time, on the other hand, is irrelevant in the measurement of echo delay.

Tools

Audio Analysis was done with the Audacity program, a free, multitrack audio editor and recorder.
Propagation predictions and MUF analysis were made with VOAPROP by G4ILO and VOACAP online, (HF Propagation Prediction and Ionospheric Communications Analysis-Online service). While the CW signal mirror analysis was done with WINRAD software.

Notes

(1) Whispering Gallery: It is an effect related to the diffusion of sound within dome vaults (for example in the Whisper Gallery inside St. Paul's Cathedral in London) in which the sound follows the edge of the wall, continuing for subsequent reflections with low attenuation. This mechanism applies to both light waves and radio waves and therefore by analogy within the Ionospheric duct that we hypothesized in this document.

(2) Possible different paths from the great circle to the traditional antipodal long path. We have seen there may be different paths than the great circle, with the formation of shorter Ionospheric ducts than the grand circle line as evidenced by the reception of echoes with delays even considerably less than you would expect compared to a signal that has traveled the classic long path line along the great circle.

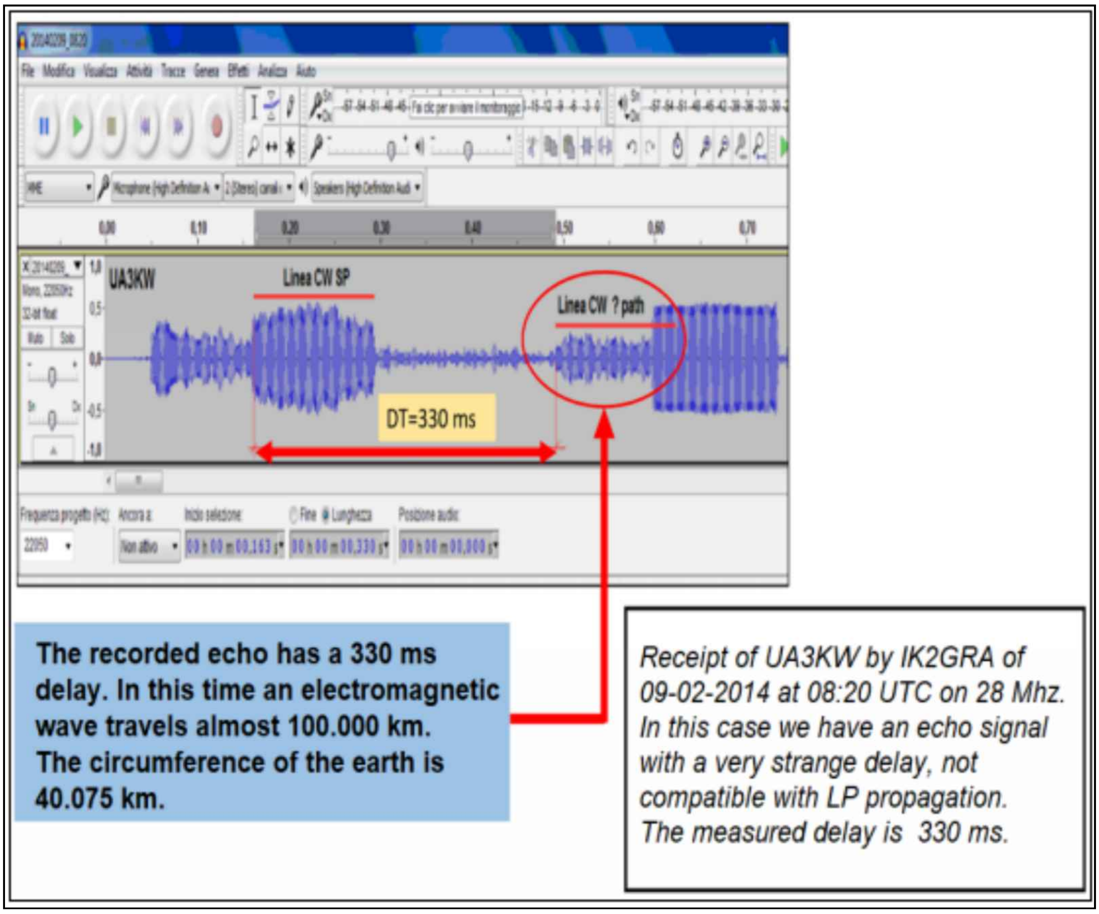
(3) VOACAP MUF: In the VOACAP program, the MUF parameter (Maximum Usable Frequency) is a statistical concept and is defined as the maximum usable frequency mediated for a given ionospheric path, month, time, and SSN number of sunspots. On each day of the month at a given time, there is an observed maximum frequency (MOF) for a mode. The average of this distribution is called MUF. So, in this case the MUF is not the maximum frequency that can be used in terms of communication. In other words, the MUF is the frequency for which the ionospheric connection is expected on 50 % of the days of the month.

(4) LPP mean Long Path continuation: long path is a signal that propagates in the opposite direction to the short path SP. LPP, is the signal that propagates for another lap of the earth.

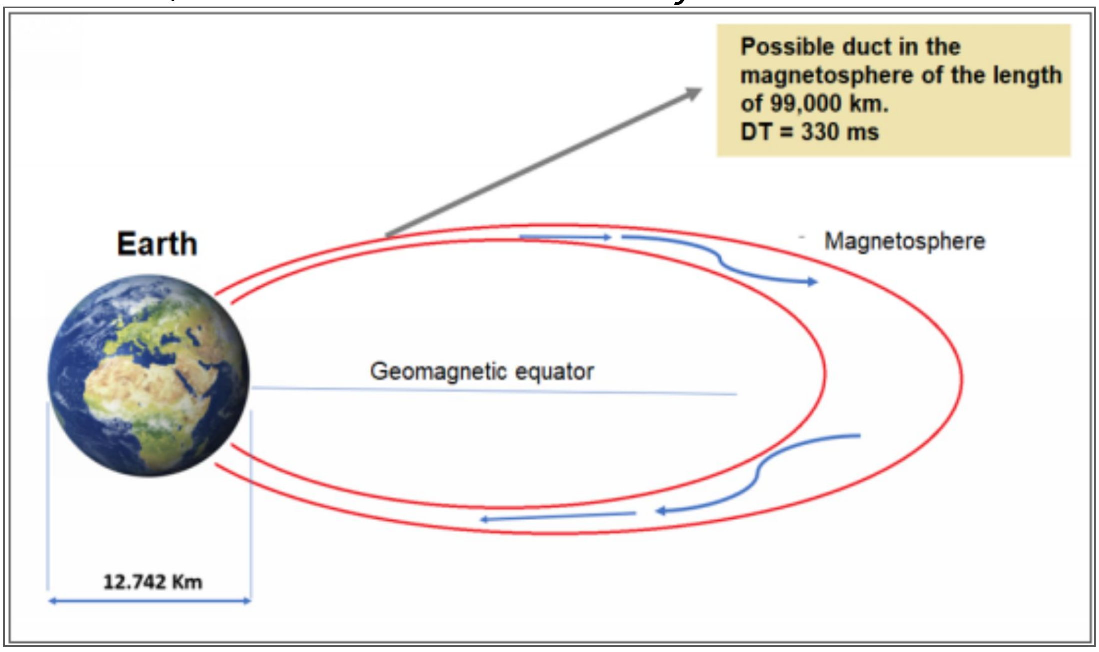
(5) Periodic undulations of the Ionosphere attributable to TID Travelling Ionospheric Disturbances, which are waves that propagate in the ionosphere in the form of waves.

Mysterious echoes

This is one of these cases where it is difficult to find an explanation. It is the recording of UA3KW on 09-02-2014 at 08:20 UTC in 28 MHz, by IK2GRA. In the figure below we can see the line I called "CW Line SP", written on top of a continuous red line that I used to measure the length of the line. They pass 330 ms and the same line reappears, but overlaps a new line transmitted by UA3KW. We are in the presence of an echo with an abnormal delay. They are not the usual 140 ms about explainable with the long path, but in this case, I recorded a dt of 330 ms. In this time, an electromagnetic wave traveled for almost 100,000 km.
This is a distance two and a half times longer than the entire earthly circumference. This type of echo is close to the category of LED, long delayed echoes. They are radio echoes which return to the sender several seconds after a radio transmission has occurred. Delays of longer than 2.7 seconds are considered LDE. They have several proposed scientific origins.



One of the possible explanations of these anomalous echoes could be in this study conducted by an Australian scientist, Cleo Loi. This is the story.



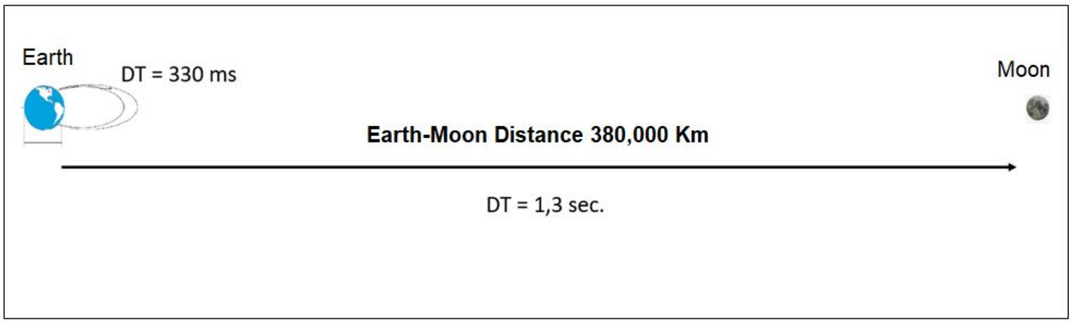


Fig. Graphical hypothesis of a duct in the magnetosphere having a length of almost 100,000 kilometers. Both figures are to scale. The figure below shows the relative distance of the moon to the earth for an average distance of 380,000 kilometers. An electromagnetic wave takes about 1.3 seconds to reach the moon. The magnetosphere extends for thousands of km in space, from the day side (the illuminated part) it reaches 60,000 km of extension, under the pressure of the solar wind, while in the shaded part (the night) it can reach over 250,000 km of distance.

An explanation

One of the possible explanations of these anomalous echoes could be in this study conducted by an Australian scientist, Cleo Loi with whom I had the opportunity to compare myself. I report the entire story below. In June 2015, an Australian scientist from the University of Sydney, Cleo Loi, made a remarkably interesting discovery about the discovery of plasma tubes

in the magnetosphere. Using a radio telescope that allows you to look at space in 3D, you have shown that these plasma conduits can form inside the ionosphere. This is a sensational discovery that could also change the theory of the structure of magnetic fields. The research was published under the title: "Real-time image of high-density conduits between the plasmasphere and ionosphere" by Cleo Loi- University of Sydney with the support of some members of the Murchison Widefield Radio Array (MWA) international consortium. What could be the role of these structures in HF radio propagation? I wonder if this discovery may have a connection with my research on long path propagation and ionospheric conduits.

A speculation: Slowing of the radio wave?

Could there be a slowing down of the radio wave while crossing certain super dense areas of the ionosphere? The electromagnetic wave is equivalent to a light wave, what changes is the wavelength. Passing through materials, light undergoes optical dispersion events and in many cases, it propagates with a speed lower than c0, by a factor called the refractive index of the material. The speed of light in air is only slightly lower than c0 (c0 is the speed of light in vacuum and is 299.792 km / sec). Denser materials, such as water and glass, slow down light to fractions equal to 3/4 and 2/3 of c0. There are also particular materials, called metamaterials, which have a negative refractive index. The light seems to slow down due to an inelastic impact: It is absorbed by an atom of the material passed through which is excited and returns the light in a delayed and deflected direction. In 1999, a group of scientists led by Lene Hau was able to slow the speed of a beam of light down to about 61 km / h. In 2001, they were able to momentarily stop a beam. See: Bose-Einstein condensate for more information. In January 2003, Mikhail Lukin, together with scientists from Harvard University and the Lebedev Institute in Moscow, managed to completely stop the light inside a gas of rubidium atoms at a temperature of about 80 ° C: the atoms, to use the words of Lukin, "they behaved like small mirrors" (Dumé, 2003), due to the interference patterns of two "control" rays (Dumé, 2003). In July 2003, at the University of Rochester Matthew Bigelow, Nick Lepeshkin and Robert Boyd both slowed and accelerated light at room temperature in an alexandrite crystal by exploiting changes in the refractive index due to quantum interference.

Behind all visible laws and connections, something subtle, intangible and inexplicable remains. (Albert Einstein)

The research of Cleo Loi – University of Sydney

In June 2015, the Australian scientist of the University of Sydney, Cleo Loi, has made the remarkably interesting discovery of plasma tubes in Earth's magnetosphere. Using a radio telescope that allows watching the space in 3D, she has shown that the earth's atmosphere is integrated with these plasma ducts. It is a sensational discovery that could even change the theory of the structure of the magnetic fields. The research was published under the title: *“Real-time imaging of density ducts between the plasmasphere and ionosphere”* by Cleo Loi of The University of Sydney with the support of some members of the international consortium of the Murchison Widefield Array (MWA) radio telescope. What could be the role of these structures in the HF radio propagation?
I am wondering if this discovery can have a connection with my research on the long path propagation and ionospheric ducting, that I have introduced in this chapter.

The Plasma tubes in the ionosphere

The complex plasma ducts are created by the atmosphere, when this is ionized by sunlight. These tubes are in the ionosphere, which is a multilayered plasma environment of electronically charged particles. This plasma interacts with the earth's magnetic field, creating field-aligned ducts of plasma. These structures of plasma are at about 600 km above the Earth's surface, in the upper ionosphere and they are continuing upwards into the plasmasphere (inner magnetosphere). They are positioned in a striped pattern, some stripes at high plasma density and some other at low plasma density and they are supposed to move very slowly and parallel to the Earth's magnetic field. These structures are also important because they cause signal distortions that could affect trans-ionospheric communication (satellite and GPS) and even in EME (Moon bouncing), as I could notice in several studies about this type of propagation.

The Geometry of the Tubes

Some information about the geometry, which we can use to infer the length of the tubes. They are placed at 570 +/- 40 Km above the earth's surface and the length of the magnetic field lines (according to some rough calculations) for this shell is about 14000 km for the portion above the surface of the Earth. If the ducts do indeed follow the magnetic field lines all the way around to the other hemisphere, then this is how long they would be, but the MWA observations alone cannot directly confirm this, since the array can only see a several-hundred km wide region of sky above Western Australia. The observations alone show that they are at least several hundred km long, since this is the width of MWA field of view, and over this length scale it does look as though they are very well aligned with the geomagnetic field. Now given that they exist at altitudes where the field-aligned conductivity is infinite, it is very likely that they extend into the conjugate ionosphere. So, by an educated guess I would say they are around 14000 km long. Could the tubes be misaligned with the magnetic field? To answer this question, I contacted Dr. Cleo Loi. Dr. Loi and colleagues, they are about to push through some more observations of density ducts. What they see is that at the point of formation, the tubes are aligned with the field, but successively can become distorted. They think the distortion might be the result of neutral winds in the thermosphere that are dragging the feet of the ducts along and shearing the whole structure.

The Telescope

The Murchison Widefield Array (MWA) is a low-frequency radio telescope and it is located at the Murchison Radio-astronomy Observatory (MRO) in Western Australia. The MWA consists of 2048 dual-polarization dipole antennas optimized for the 80-300 MHz frequency range, arranged as 128 "tiles", each a 4x4 array of dipoles. The Collecting area is Approx. 2000 sq. meters and Spectral resolution of 40 kHz. The MWA will be operated remotely through an interface to a Monitor and Control software package resident on a dedicated computer located at the MWA site.

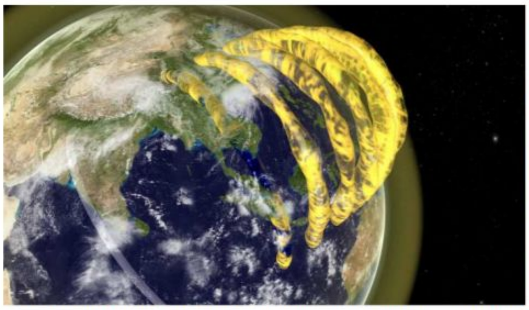


Fig.1a: Plasma tubes in the earth's magnetosphere. Image credits: CAASTRO-Mats Björklund (Magipics)
Fig.1b: The wide field array consists of 128 antenna "tiles" over a seven-square-kilometer area at the Murchison Wide Field Array radio telescope in Western Australia used for this research. Ms Loi divided the array into two halves using the western half like a right eye and the eastern half like a left eye. Similar to the way humans use sight, she used triangulation to build a three-dimensional dynamic map of the plasma tubes over a large area. (Image credits: Wikipedia – Author: Natasha Hurley-Walker)

Ionospheric Ducts

I am convinced that the HF propagation in the ionosphere does not always occur according to the classical model of ionospheric jumps, but in most cases, there is a phenomenon of ionospheric ducting. The high plasma density of the duct is capable of trapping radio signals. The radio wave follows a spiraling motion within these tubes with exceptionally low attenuation. Moreover, propagation should often occur towards trans equatorial path, considering that the lines of force of the magnetic field are oriented from north to south. The circles cannot always pass through the center of the earth. It is also possible that the signal can make more than one revolution within the duct. The formation and the efficiency of the ducts are much greater when the geomagnetic field is quiet. The ducts form for certain frequencies, from long wave to short wave, the height of the ducts is variable, and the delays are related to the frequency and height of the duct. I observed the event when the operating frequency was near the F2 critical frequency. The existence of these geo magnetically aligned structures with a density range of sizes, exist in the near-Earth plasma environment, including 10 -100 km-wide ducting structures, is consistent, with studies conducted by Murchison Widefield Array and published in the Journal of Geophysical Research.

Conclusion

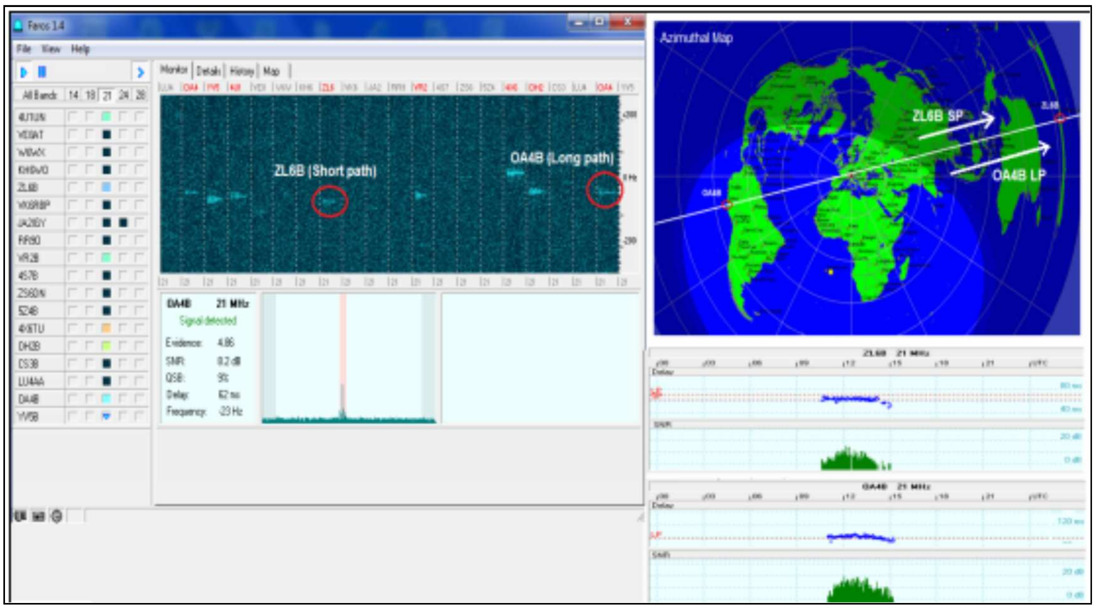
It is not clear which processes can produce echo ducting conditions in the Ionosphere. Further studies are needed to understand the impact that this discovery can have on HF radio propagation. The tubes of plasma may also explain the phenomenon still controversial of LDE, long delayed radio echoes.

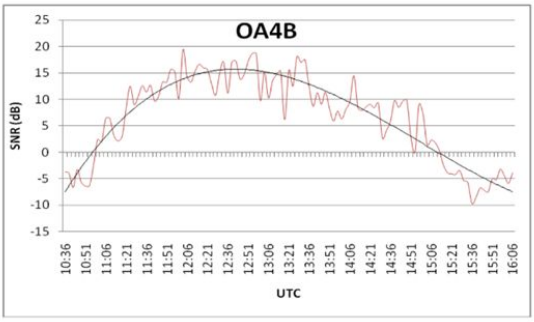
Acknowledgment

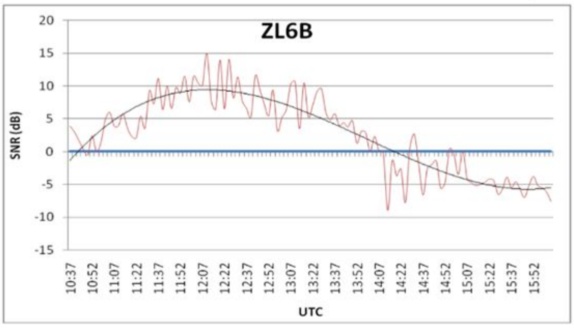
Special thanks to Cleo Loi, Australian astrophysicist, graduate at the University of Sydney School of Physics. She has a PhD in Astrophysics from the University of Cambridge. She is credited with proving the existence of plasma tubes inside the Earth's magnetosphere and extending into the plasmasphere. She provided me with material and some other information.

Studies with Faros software (beacon monitors)

I tried to analyze a long path/Short path propagation using the "Faros" beacons detection software. This program in addition to recording beacon listening, also provides other interesting parameters such as signal SNR level and propagation delay, so it can select whether the signal arrives via short or long path. The experiment described below was done in 21 MHz band on 7/11/2014 with Solar Flux SFI=136 and KP=2. The goal of this experiment is to detect the existence of a propagation duct capable of covering the entire earth's geodesic line, centered in this case on my QTH. The simultaneous reception of the ZL6B beacon heard via SP and OA4B heard via LP is a confirmation of the existence of exceptionally long propagative ducts that can cover the entire circumference of the Earth. As seen in the image below, the two beacons are found along the same geodesic line. The map is azimuthal. Unfortunately for a momentary equipment anomaly, the CS3B beacon located in Madeira along the same line, is out of service. Faros recording protocol, in the case of simultaneous reception of the beacon via SP and via LP, chooses the strongest signal.





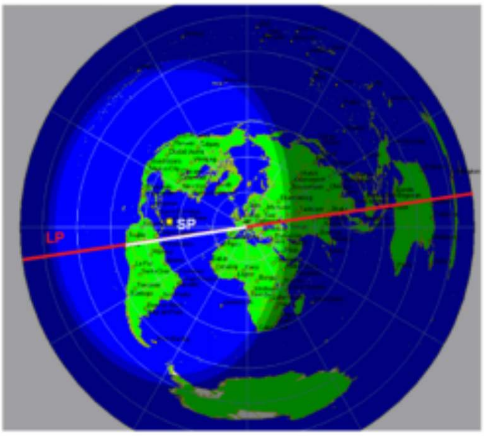


Trend of the beacon signal

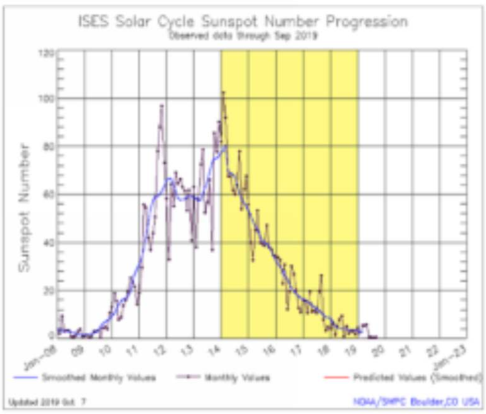
Graph of the trend of the two monitored beacons. **OA4B** has always been received long path, while beacon **ZL6B** has always been received short path (except some long path passages of short duration). The black curve represents a polynomial line that highlights a Gaussian trend of the signal.

Study of long path echoes and anomalous paths

I continued to make observations on the behavior of the ionosphere with attention on long path propagation by monitoring the beacons of the NCDX Foundation. With Faros software (note 3). I focused my attention on the OA4B beacon in Lima, Peru because it had abnormal behavior that I will talk about in the next pages. Carl Luetzelschwab also detected the same anomalous behavior, K9LA, on another beacon, ZL6B. This confirms a repetitive phenomenon independent of geographical location and frequency, of oblique pathways caused by ionospheric abnormalities. These experiments date back to 2014, during the last peak of the solar cycle, and conclude a series of observations that lasted more than five years, during which I recorded various ionosphere anomalies, which are more frequent in the high phase of the solar cycle. The azimuthal map for beacon OA4B, showing long path (red segment) and short path (white segment). The LP distance is about 29,000 km, and the SP is 11,000 km. The figure at right below on solar cycle 24, yellow shows the period where the observations were made for this study.



Azimuth map for the OA4B beacon, showing the long path (red segment) and the short path (white segment). The LP distance is 29,000 km and the SP distance is 11,000 km.



Solar cycle 24: The time period where the observations for this study were made is highlighted in yellow

Description of the event

The figure on the following page shows the full day recording of the OA4B beacon from Peru. We can see that the beacon begins to arrive around 14:00 UTC via LP, then

around 15:00 UTC the reception becomes multiple that is sometimes LP and sometimes SP, see red box called “instability area”. The most interesting thing is the two blue points, that is, the receptions around 15:50 UTC when the path was not either SP, or LP but it was something different. The delay for these two receptions is about 64 ms (see note 1) which is more than 20 ms compared to the short path delay. This means that the signal has been diverted more than 6000 kilometers from the direction of the great circle via SP. The intermediate values of the delay suggest an anomalous path, i.e., oblique, where the signal is misalignment several degrees from the great circle (see note 2). In this transition area, we have a multipath zone of instability, difficult to understand. During the transition phase between the long and short path, something happens in the ionosphere. What is is this? and what is the path of the signal in the ionosphere?

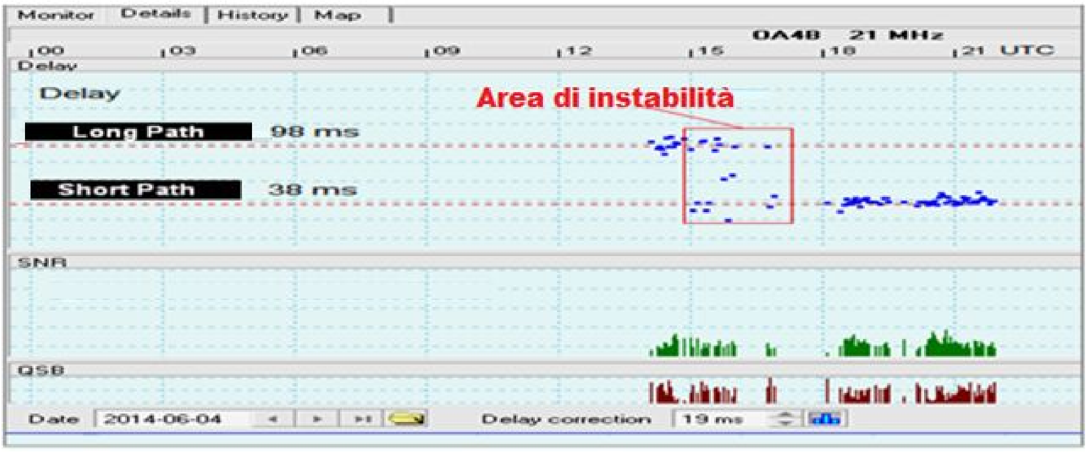
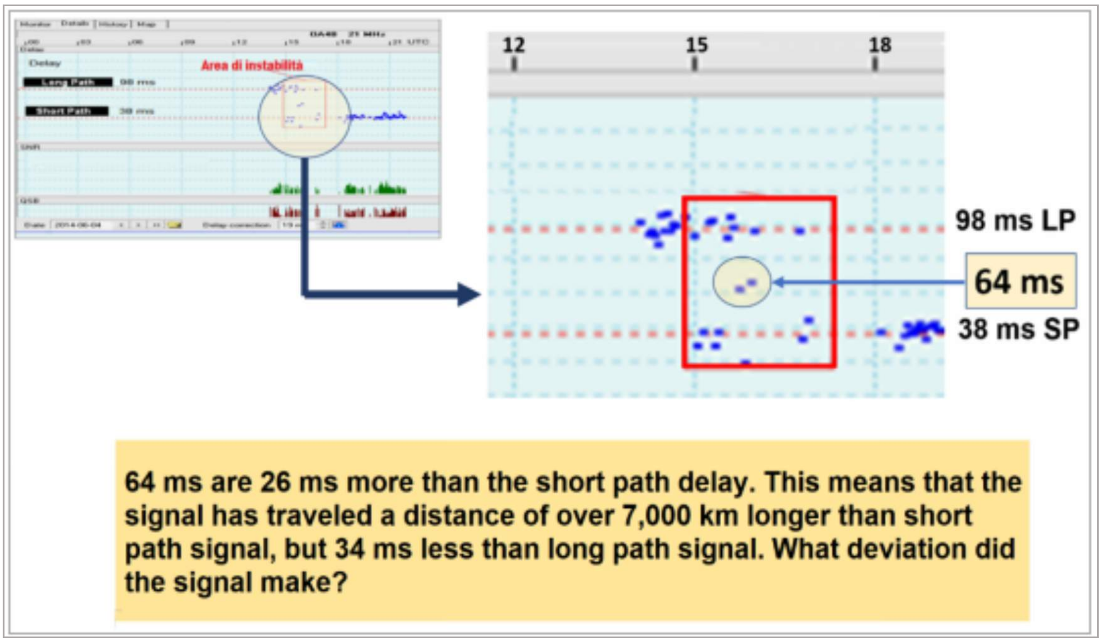


Fig. Faros software panel for receiving OA4B from IK3XTV:04/06/2014 FREQ. 21 MHZ - Kp = 1 - Solar flux SFU = 107- ssn = 61. The graph shows the zone of instability detected in the transition from LP to SP Between about 15 and 17 UTC, the propagation then closes until 18 UTC and then reopens permanently until 22 UTC, but only via SP. The graph below with the green bars, shows the amplitude of the signal, highlighted as SNR, signal-to-noise ratio. If we look at the amplitude of the Long Path signal and compare it to that of the short path, we see that the difference is only a few dB. (The software used is Faros for

automatic beacon monitoring (www.dxatlas.com) and the antenna is a simple G5RV).



Paths out of the great circle

Deviations from the great circle of radio signals propagating in the ionosphere are very difficult to explain. The theory suggests that deviation can occur along the equator or near polar areas, when signals lap the auroral oval but I don't think that's always the case. In figure of the OA4B beacon, it can be noted that Around 15 UTC there is an area of instability in which the beacon is sometimes received via LP and sometimes via SP. We must also consider that if the software simultaneously receives two signals, one LP and the other SP, it is programmed to record the strongest signal. Having this alternation would mean open propagation along the entire circumference of the Earth. Basically an ionospheric duct. In other papers, in fact, I have talked a lot about these ionospheric ducts. In the case shown in the figure of the

My considerations and a possible explanation

The ionosphere is not a homogeneous refractor. It is a murky and irregular heterogeneous and constantly evolving region with many areas with different ionization densities. There are more dispersions and irregularities

than most of us have ever thought or imagined. The general mechanism that causes waves deviated from the path of the great circle are the more or less horizontal ionization gradients with unequal thickness. Signals traveling in a layer with a higher degree of ionization will be refracted depending on the gradient inclination, the wave will move at an angle other than the direction of the grand circle. So with that in mind, there may have been a point in the ionosphere, probably in the equatorial zone where the highest electron densities occur and where electron density gradients can be significant and where there may therefore have been a point of reflection capable of diverting the path. Note that both cases analyzed occurred in a period of high solar activity and the mechanism appears to be frequency independent (14 MHz and 21 MHz). These deviations, or anomalous reflections, are relatively common and I have recorded several cases in the course of my ham radio activity.

About beacons

OA4B: Lima is located in the central coastal part of Peru, overlooking the Pacific Ocean, in a flat area near the Andes Mountains, with peaks very high over 6000 meters above sea level in a not favorable position towards Europe.
Coordinates: OA4B Lima-Peru Lat: 12 04 S Long: 76 57 W.
ZL6BB: The beacon is located in a flat area in the open countryside.
Coordinates: ZL6B Masterton-New Zealand Lat: -41,043 N Long: -175.59 W.

FT8 Experiments - Sidescatter Propagation

I would like to describe this anomaly that I have encountered several times. The figure on the following page describes a QSO with a Swiss station received the antenna pointed towards South America, 60 degrees azimuths of offset error compared to the pointing directed towards Switzerland. At that time, the 15 meter band was open to South America. That was the direction with the highest MUF. HB9TVS also beamed with his 4-element Yagi

antenna, pointing towards South America, looking for FT8 contacts. I have experienced many cases similar to this, including with other stations, for example German, Dutch and British stations. I have also ruled out possible reflections on the mountains. I wonder whether this phenomenon is related to what is described in this document.

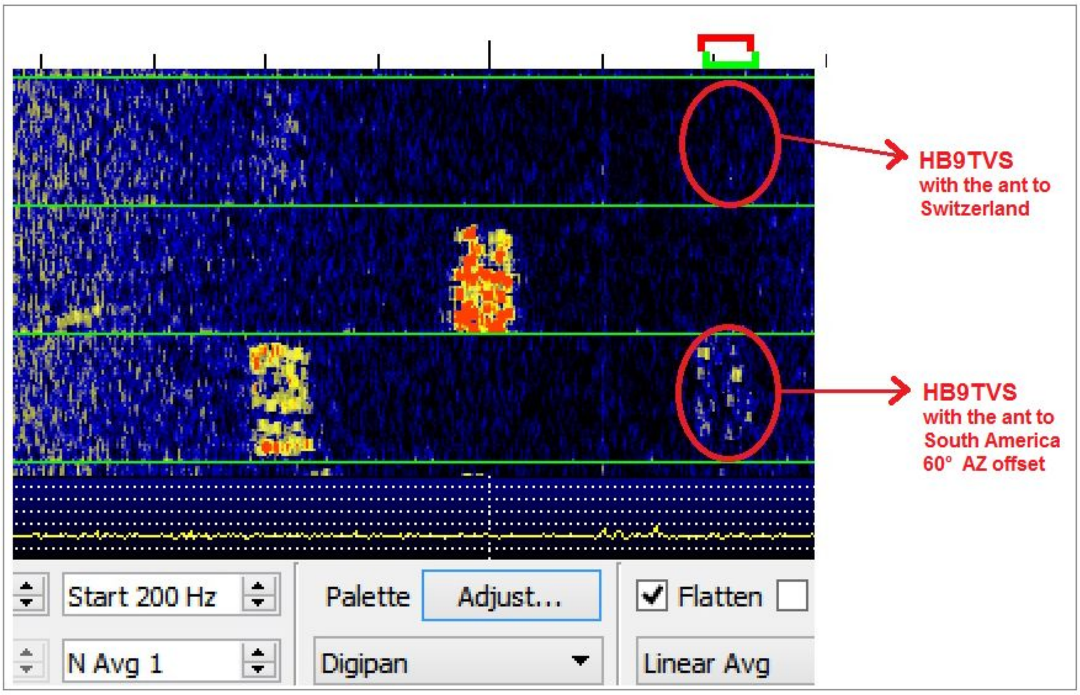


Fig. Screenshot of FT8, with the trace of HB9TVS during my QSO on April 25, 2018 on the frequency of 21 Mhz. The signal was receive only by pointing the antenna to South America and not heading to Switzerland. In the upper right part you can see that the HB9TVS signal disappears with my antenna towards him, while you see in the lower right that the signal increases with the antenna towards South America.

The big question is, where does the signal reflect? it is difficult to answer this question with absolute certainty. The possibilities for reflection are:

1- In the ionosphere due to a local increase in the ionization gradient.

2- On the surface of the sea (good conductivity of salt water).
3- On the Earth's surface (but consider the low reflection capacity, only about 7% of energy is reflected back from the soil).

I can assume that reflection occurs in the ionosphere due to the high gradients in electron density at that time and in that direction, but reflection on the sea and scattering on the ground are also plausible explanations. There must be a mechanism equivalent to an electronic density gradient in order to change the direction of an electromagnetic wave when it encounters the sea or land. A flat, smooth sea cannot change the direction of the azimuth, so this suggests that there must be waves in the scatter zone. Similarly, smooth flat terrain cannot change direction, so this could happen in the presence of valleys, hills, or mountains at the intersection point. The dispersion coefficients of the Earth's surface can be quite variable, depending on the nature of the surface and the elevation angle.

Side scatter experiments with german station DH1TT of August 11, 2019 – 17:17 UTC

The experiment done with DH1TT is similar to the one already described and done with another German station, DJ2HK in 2004. It is important because it seems to highlight that there is a fairly stable and regular reflection on some earth's surface. Land or sea. Both my signal and the DH1TT signal were not affected by any kind of fading. The DH1TT signal arrived 5/8 at my station and my signal arrived 5/2 in Germany. The experiment with DHI1TT, was repeated several times, with the same results.

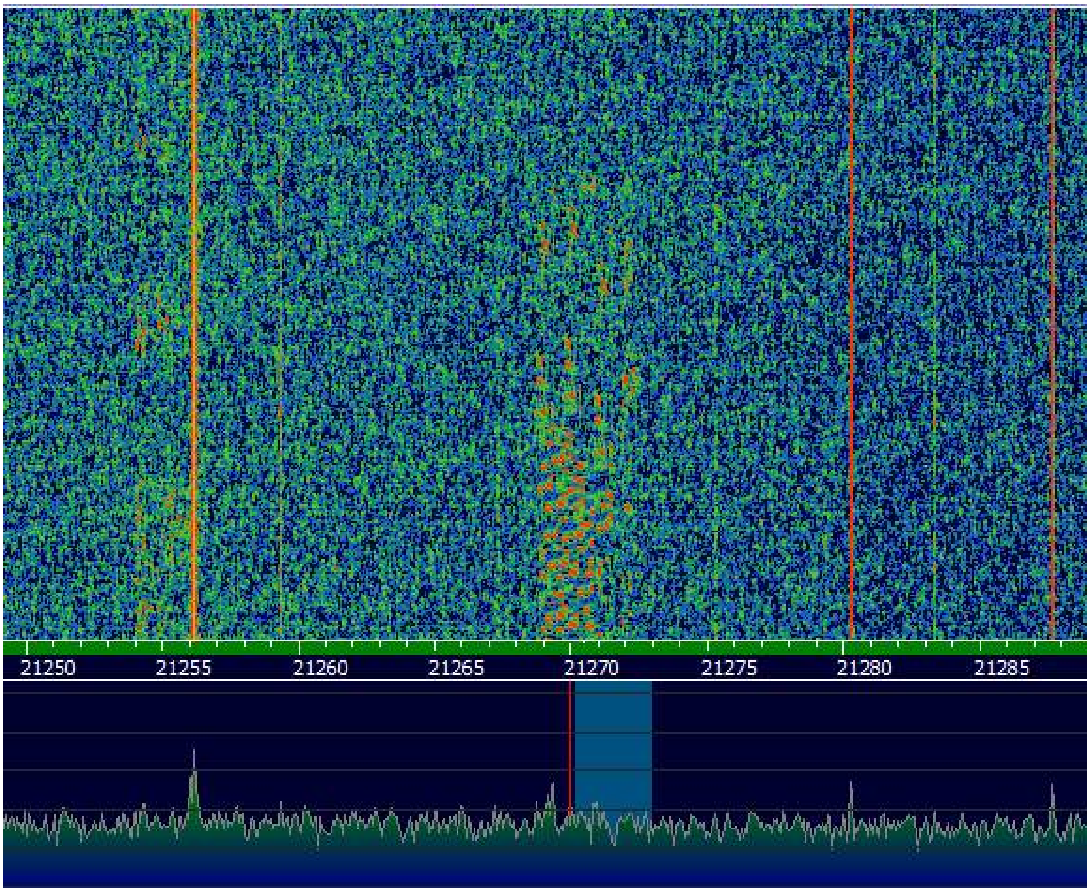


Fig. SSB signal on WINRAD by DH1TT that transmits with a Yagi 6 single-band elements for the 21MHz 6el. and 750 W. IK3XTV with Yagi monoband antenna 2 el. for the 21 MHz and 100W. both antennas pointed southwest towards Spain. Date: *(August 11, 2019, 17:17 UTC).*

Image: screen shot from HDSDR software. HDSDR is a freeware Software Defined Radio (SDR) program.

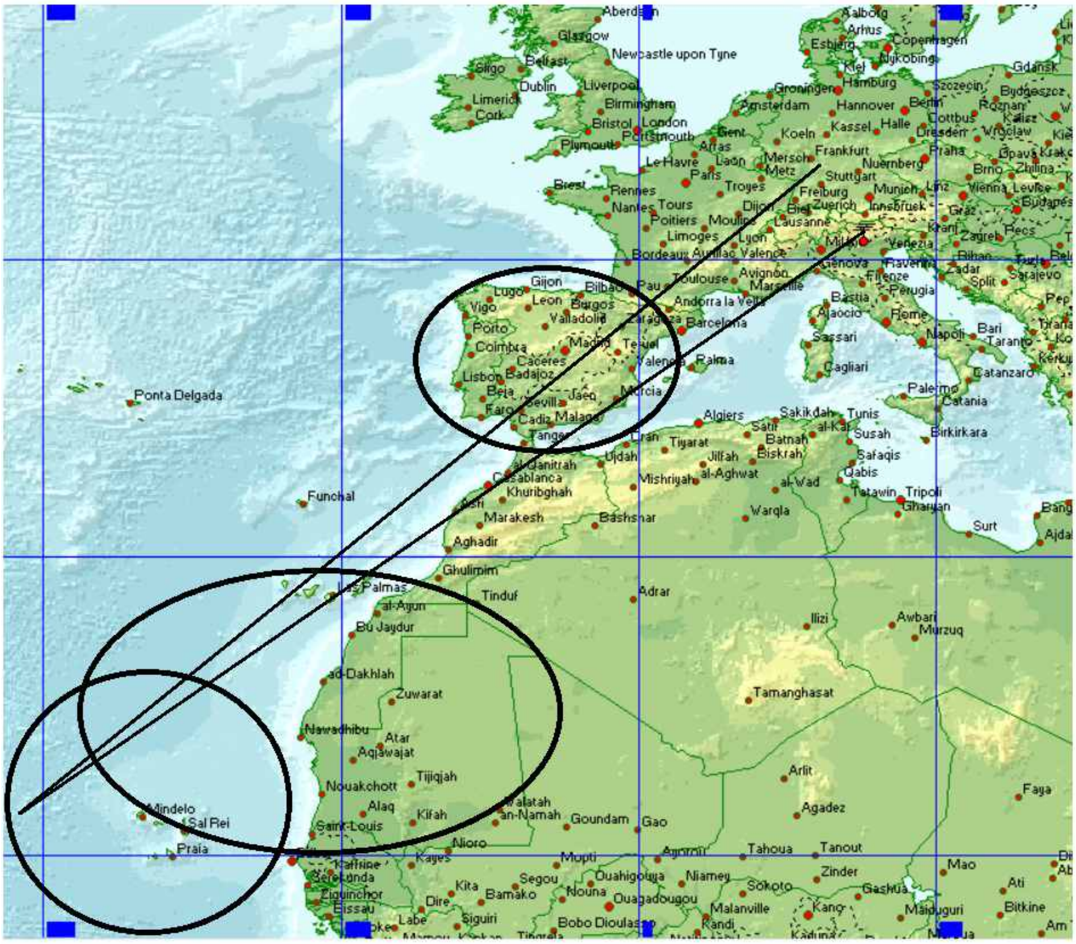
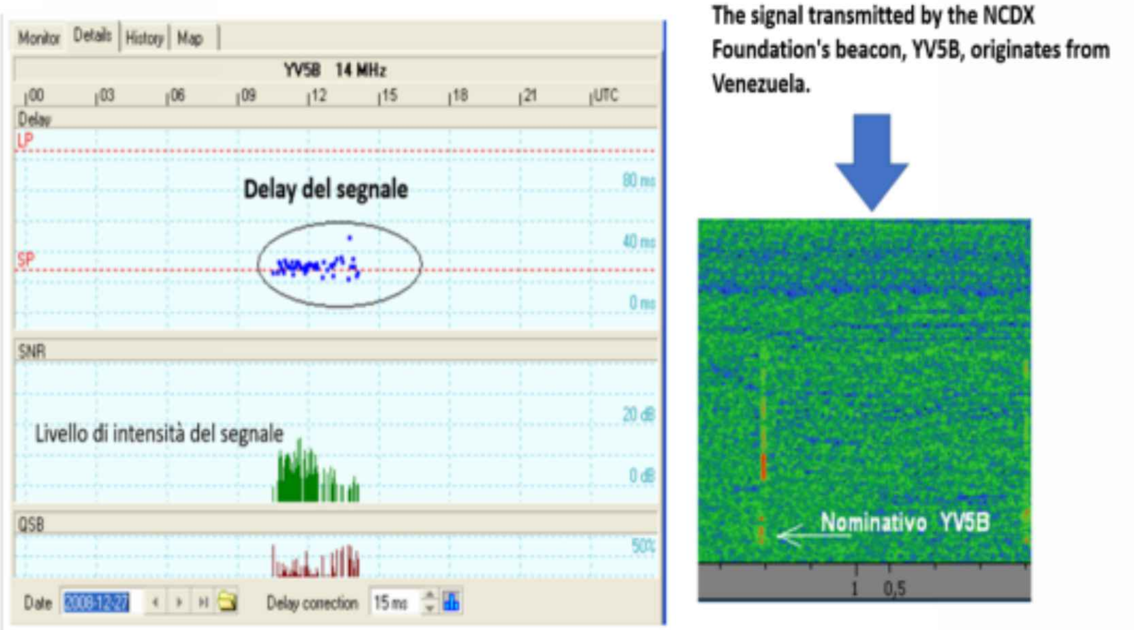


Fig. Geographical location of the stations and some possible areas of dispersion. The first is located on the Iberian Peninsula and the second on the Atlantic Ocean, in the Canary Islands area or perhaps in the Sahara Desert.
Map created using the DX Atlas software, www.dxatlas.com.

Congenital instability of the ionosphere: Another strange phenomenon



The beacon signal delay remains stable as long as the ionospheric propagation is good. However, when the ionosphere starts becoming unstable and the signal intensity decreases, the received signal delay from YV5B begins to vary with oscillations in the range of +/- 20 ms. It is worth noting that in 20 ms, an electromagnetic wave travels approximately 6000 kilometers.

Margherita Hack used to emphasize that the joy of scientific research lies in continually seeking new frontiers to conquer, constructing more potent investigative tools, formulating intricate theories, and perpetually progressing, all while recognizing that the pursuit of understanding reality draws one ever closer without complete comprehension. In my experience, this sentiment holds true, as I persist in observation and exploration without ever fully attaining absolute understanding. Another phenomenon I have frequently observed is described below, revealing a congenital instability within the ionosphere that results in nonlinear behaviors, as evidenced by the "Faros" software. This phenomenon can be explained as follows: Consider the case of receiving the YV5B beacon from Caracas, the capital of Venezuela, transmitting on the frequency of 14 MHz. Initially, the beacon's signal arrives robust, unwavering, and without path delays. However, as the quality of propagation

diminishes and the ionospheric conditions along the path become unstable, the signal delay experiences variations on the order of 20 ms, as depicted in the graph below. This recurrent occurrence has been observed with numerous other beacons across various frequencies. In a way, it shares a connection with the aforementioned phenomenon, although in this instance, it isn't directly associated with the transition between the short path and long path propagation routes.

Conclusion

An electromagnetic wave travels in a straight line (on a large circular path) unless it is refracted, reflected, or dispersed. So those intermediate delays between long and short route probably consist of two large circular paths connected with a refractive point (or reflection).

Notes:

Note 1- The calculation of delays comes from the length of the path divided by the speed of light. Short route between OA4B and IK3XTV is 10,850 km. The speed of light is 300,000 km/s, so the delay is 36.2 ms. Similarly, the long route is 29,174 km divided by 300,000 km / s = 97.2 ms. while the delay of 64 ms corresponds to a length of the route of 19,200 km

Note 2- A large circle is the shortest segment connecting two points on the Earth's sphere

Note 3- Faros software continuously monitors 18 NCDXF beacons over five bands, automatically detects beacon signal presence, and measures signal-to-noise ratio, QSB index, and signal propagation delay. automatically identifies long path openings, based on signal delay.

Ionosphere as a waveguide

Long path experiments: OA4B beacon reception (Lima – Peru)

I conducted experiments aimed at developing a potential new explanatory model for ionospheric propagation. The tests were conducted using various software tools: Faros, developed by Alex Shovkoplyas VE3NA, which is capable of continuously monitoring NCDXF beacons on multiple bands; WSPR (Weak Signal Propagation Reporter) by Joe Taylor, K1JT; and for certain transmission experiments, the WSJT program (as noted), also developed by K1JT. While originally designed for EME (Earth-Moon-Earth) communication, WSJT has also found use in digital HF communications at extremely low power levels. Faros, equipped with a high-speed internet connection that ensures accurate time synchronization through Network Time Protocol (NTP) servers, can detect both short-path and long-path propagation. Numerous instances of long-path openings have been recorded. However, it is noteworthy that the beacon often remains audible via the short path at the same time. This phenomenon implies a full Earth's circumference propagation. Sometimes, the long path signal is stronger, while at other times, the short path signal prevails. Enhanced ionospheric conditions during the upper phase of the solar cycle have demonstrated that signals can travel more than one circuit (a condition validated through experimental confirmation). Similar experiments focusing on the ZL6B beacon corroborate this behavior. While observations frequently center on the 18 MHz band, analogous behavior has been documented on other bands, particularly 20 meters. Notably, propagation often concurrently opens for both ZL6B in New Zealand and VK6RPB in Perth, Australia. This alignment suggests the presence of a "favorable path" within the ionosphere, as all three beacons align along the same geodesic line. This phenomenon implies the possibility of a guided wave

circuit or propagation mechanism within the ionosphere, even during periods of low solar activity. It is observed that longer wave guides lead to shorter openings, due to the rapid changes in the supporting conditions. While rooted in experiments conducted within this specific geographic region, these findings can potentially be extrapolated to a global scale, suggesting a pattern of ionospheric behavior across the entire planet by analogy.

Date: 12.12.2008 - 11.30 UTC

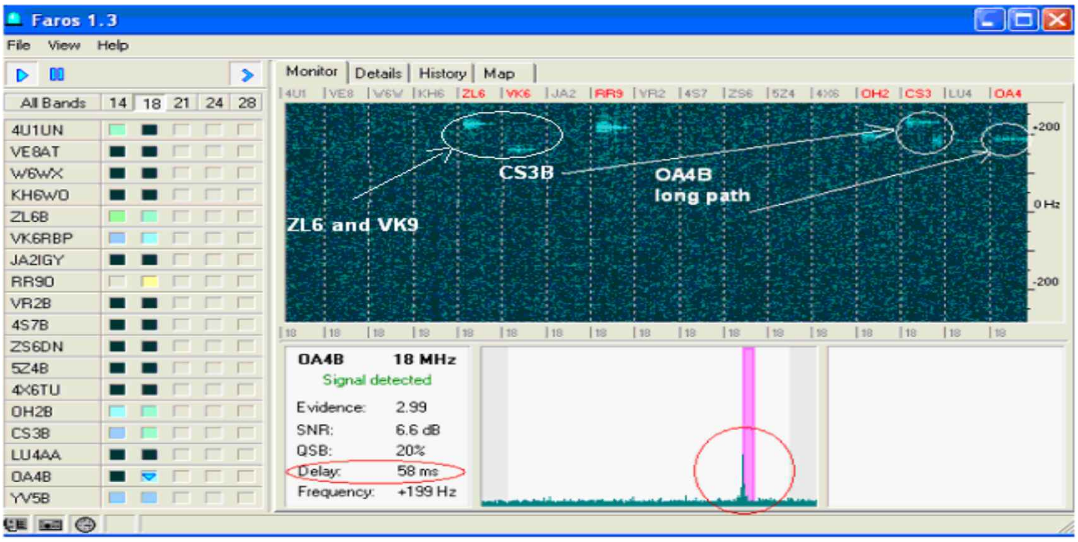
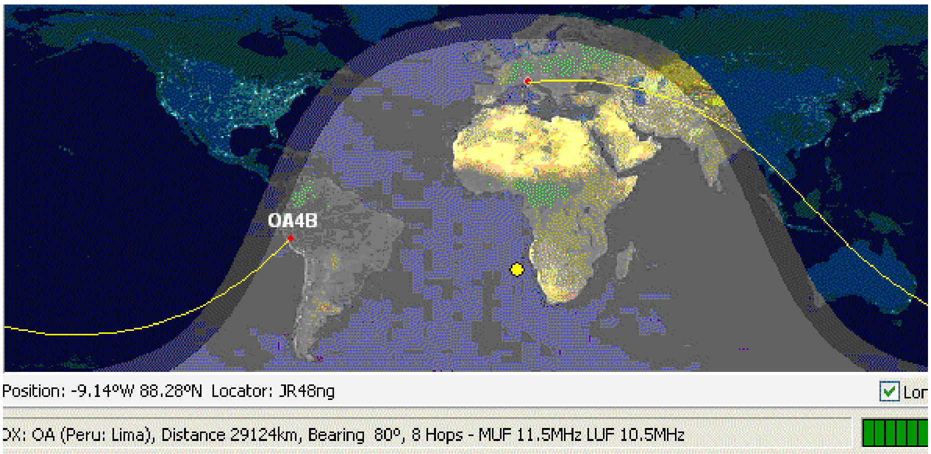


Fig. Screen shot image from Faros software. www.dxatlas.com

Hypothesis: The ionosphere as a waveguide.

In this paper it is hypothesized that HF propagation is possible because of waveguides forming in the Earth – ionosphere system (the ionosphere could behave like a ground-ionosphere cavity) the signal propagates within the duct, with an exceptionally low loss or even a gain, following Snell's law describing how to refraction a light beam in the transition between two means with different refractive index

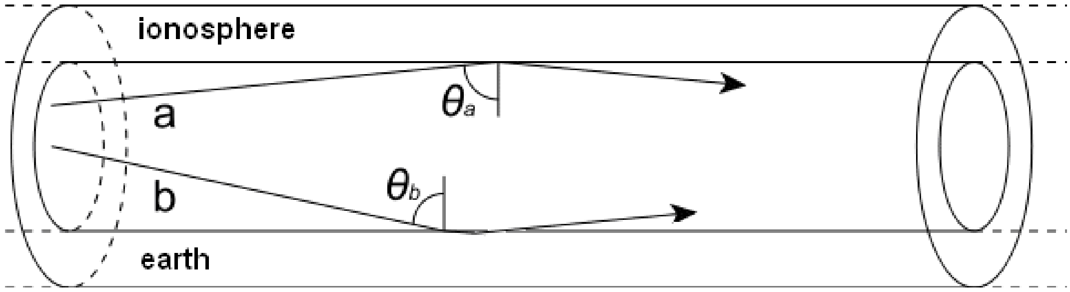


Pipelines in the Ionosphere

The propagation of radio waves is governed by Maxwell's equation which establishes the spatial and [temporal]() evolution of electric [and]() magnetic fields and which in extreme synthesis states that the field intensity of an electromagnetic radiation decreases according to the inverse of the square of distance (law of the inverse of the square). The inverse square law applies to fields that propagate evenly in all directions (e.g., light, magnetic field, and gravitational field). Bodies capable of producing such fields are called point sources. Given the low power in play related to the very long distances of amateur radio connections, only a low-leakage system could guarantee communications. Various experimental observations tend to confirm that

the Ionosphere behaves like a waveguide, and HF propagation takes place in the same way as the propagation of light within an optical fiber, as assumed by Yuri Blanarovich, VE3BMV, which he describes in an excellent article that I found on the internet *"Electromagnetic wave propagation by conduction"*. A similar mechanism in acoustic physics is known as the whispering gallery effect. Moreover, the analysis of theoretical losses along the way on even very low-power transmissions made in HF with Joe Taylor's JT65A digital system, K1JT, show that propagation can only be supported by a low-attenuation system as a wave guide can be or even with a possible congenital self-amplification (e.g., slow-acting focus). These properties of the ionosphere were originally studied and applied for the study of atmospheric noise in the ELF and VLF bands generated by lightning propagating within the ionospheric cavity with extremely low attenuation. It is clear, however, that the wave guide is not always active, indeed it can only be activated at certain times as the guide is not homogeneous and depends on the length of the path made by the signal and the characteristics of the propagation medium (such as electronic density and static magnetic field) indeed the longer there are irregularities such as day/night discontinuity. In any case, the connection is possible only when a long guide is activated (e.g., shadow zone). The activation mechanism is determined by the ionization of the sun. The system described, however, refers to a simplified model, we are faced with a much more complex model. The ionosphere is not a linear system, and this complicates things, in fact the ionosphere is a plasma immersed in the Earth's magnetic field and subjected to solar radiation pressure. In fact, we must consider that the principle of superposition of the electromagnetic wave induces space to be linear, but the Earth's ionosphere is far from a linear space: how does electromagnetic radiation immersed in a

nonlinear plasma behave? Complex equations, amplification, focus, etc. should be applied.



Considerations

Studies have been conducted on suspected nonlinear ionosphere behaviors, such as or increased absorption of high-power transmitted signals compared to low power signals. Or intermodulation phenomena (e.g., Luxembourg effect). These studies have yielded results that are difficult to interpret and are still ongoing, but they are related to heating phenomena of the ionosphere. For example, it is scientifically proven that the presence of TID (traveler ionospheric disturbances) causes nonlinear behavior of the ionosphere. The one described above refers to an extremely simplistic model (image above). The Earth's magnetic field can introduce curvatures on the wave guides, which would explain various cases of azimuth deviations. Most often the intensity of the HF signals received are independent of distance, antipodal signals for example are stronger than signals transmitted from lower distances.

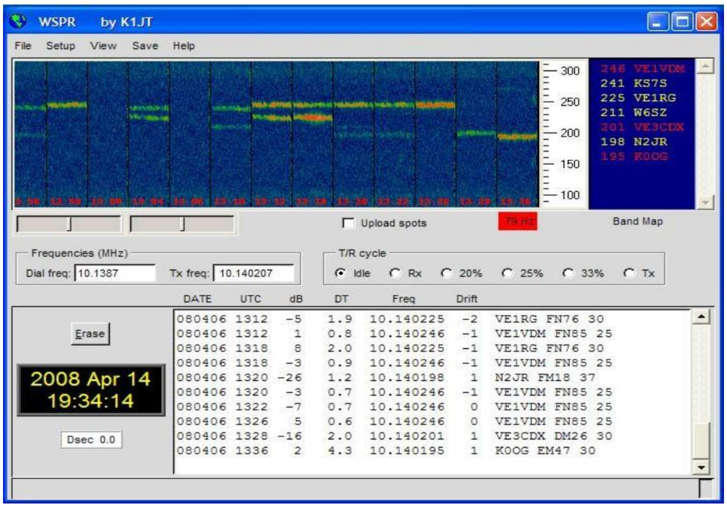
Note:

<u>1-WSPR description</u>

WSPR implements a protocol designed to study propagation with low-power transmissions. Each transmission sends the station name, the lessor and the transmitter power to dBm.

The program can decode the received signals with a noise signal ratio

S/N low (the threshold is 32 dB with a bandwidth of 2500 Hz. Stations with internet access can automatically upload the receive report to a central database, WSPRnet, which can be consulted directly, and which shows all WSPR traffic on a world map. The transmission mode is beacon type.



2- WSJT description

"K1JT weak signal communication") consists of complex digital communication protocols perfected specifically for meteor scatter, ionospheric and tropospheric propagation, and EME (Moon bounce) for VHF / UHF, and for HF connections via ionosphere. The program can decode signals level up to 29 dB below the noise level.

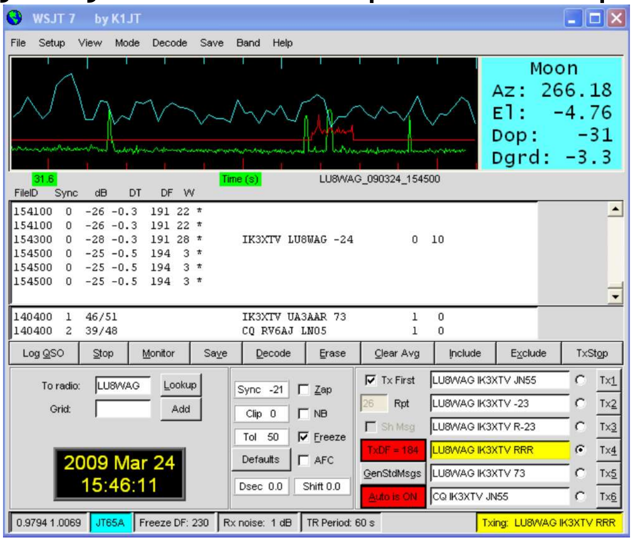
The specific communication protocols are now as follows:

FSK441 for meteor scatter

JT6M for meteor scatter especially 50 MHz and ionospheric scatter.

JT65 for EME in VHF/UHF, and for this via ionosphere in HF

JT2, JT4, WSPR: experimental protocols are currently



Experiences of a Navy officer radio operator.

IK1DQW Adolfo Brochetelli

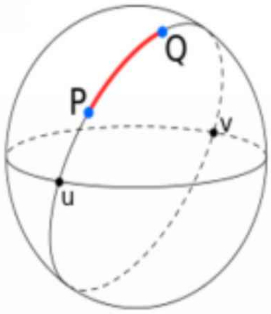
I inserted these pages in the book to give my full recognition to a radio amateur "Silent Key": Adolfo Brochetelli, IK1DQW, Naval Officer. This is the telling story of one of many stories of his invaluable experiences as a radio operator in many years spent plying the oceans all over the world. I never met Adolfo in person, but the long correspondence with him made me feel like a friend and where transpired that he was a great person. I am sorry that I did not get to know him better, because he passed away a few years ago. I want to imagine him up there, inside his ship's radio room, with his headphones and his telegraph key. Sailing on his ship, listening his radio and looking the best path propagation and watching at the infinite horizon.
This is only a is only a small piece of his "ship's logbook” a good sailor, resulting from one of the many discussions we had about propagation, about the long path and the mysterious delays in short waves.

Orthodromic path: The orthodrome represents the shortest distance separating two points and represents the shortest path and has the characteristic of cutting all meridians at different angles, along a maximum circle.
or: If the light travels the equator in 133 ms, the path of 10200 km is traveled in 34 ms.

If the transmission speed is about 90 characters per minute (including the space of one dot between letters and the three dots space between words), the accounts do not add up correctly.
The delay was such that a dot became a line, so doing the sum of the dots and the sum of the lines of a transmission with the word "Paris," converting everything into dots equals 315 dots per minute.
That is: Paris =10 dots, 4 lines. That is, 4 lines = 12 dots = 22 dots
Plus 4 dots of letter space = 10+12+4 =26 for (17x3) =1326 dots in one-minute dots issued for the corresponding speed of 90 characters per minute
So, a dot is worth 60/1326=0.045 seconds
Reconsidering that during the connection a dot was heard as a line (0.045 x 3) = 0.13 seconds. The radio wave could not travel through orthodromy - if it took 133ms.
The peak of the solar cycle (Sun max) calculated in 2012 is divided as follows over the years:
2012-11=2001-11=1990-11=1979-11=1968-11=1957-11=1946-11=1935-11=1924 (that's why Guglielmo Marconi used the frequency around 12 MHz in 1930 to switch on the Sydney lights. During sun max the world climatology changes completely. As well as the ionization of the ionosphere and the positioning of the earth magnetic field and its strength.
In the years near solar minimum, the magnetic field has another trend. How does the wavefront of the shortwave radio wave change? It changes according to the power used, the directionality of the antenna, from impacting different ducts.
I remember very well that the signal I received from Roma PT Radio on 8656.0 KHz, was strong. The signal made a continuous rhumb line rotation, or other types of mathematical calculations should be used to explain why a dot lasting 0.045 seconds became 0.13 seconds long.
The delay was therefore greater than 34 ms on a 10200 km path.

Moving away by longitude and inverse latitude, the problem persisted, and it was cancelled out only with the use of the frequency of 12 MHz, which unfortunately suffered from several factors (sunspots, solar quiet values, etc.) and, strangely enough, no longer have the reference of Sirius but of the corresponding constellation of the southern hemisphere; see a star map distributed over the 12 months for both the northern and southern hemispheres and compare the position of the constellation with the hour of the night radio contact. In the field of short waves of both 8 MHz and 12 MHz, long path and shorth path can be chimeras: It is not said that pointing the huge directional antenna for the long path makes a long path. There remains the conviction that the course of the magnetic field and the magnetosphere led the wave to make other stretches, but the large capture area capacity of a huge directive antenna does not make the problem clear.
For this reason, the French military stations based in Aurora pointed the directive antenna (3-25 MHz) at 45 degrees long path inclination towards the north pole to connect France. So, at Aurora, the French knew that with the directive pointed to that way they could take advantage of two effects:

1) *A conductive zone in the upper stratosphere or magnetosphere.*
2) *Use the ground-reflected wave (sandy/mother-of-pearl/coral) as a subsidiary pulse to increase antenna gain or a change in polarization or wavefront delay to be sure to enter an ionospheric or magnetospheric duct.*
3) *Always remember that a wavefront of 3 MHz is 80 meters and almost 12 meters that of 25 MHz.*



A diagram illustrating great-circle distance (drawn segment P-Q) between two points on a sphere, P and Q. Two antipodal points, u and v, are also shown.

The great-circle distance, orthodromic distance, or spherical distance is the shortest distance between two points on the surface of a sphere, measured along the surface of the sphere (as opposed to a straight line through the sphere's interior). The distance between two points in Euclidean space is the length of a straight line between them, but on the sphere, there are no straight lines. In spaces with curvature, straight lines are replaced by geodesics. Geodesics on the sphere are circles on the sphere whose centers coincide with the center of the sphere and are called great circles.

The determination of the great-circle distance is part of the more general problem of great-circle navigation, which also computes the azimuths at the end points and intermediate way-points.

Through any two points on a sphere that are not directly opposite each other, there is a unique great circle. The two points separate the great circle into two arcs. The length of the shorter arc is the great-circle distance between the points. A great circle endowed with such a distance is called a Riemannian circle in Riemannian geometry. Between two points that are directly opposite each other, called antipodal points, there are infinitely many great circles, and all great circle arcs between antipodal points have a length of half the circumference of the circle, or **Pi-Greco*r**, where r is the radius of the sphere. The Earth is nearly spherical, so great-circle distance formulas give the distance between points on the surface of the Earth correct to within about 0.5%

By Wikipedia

FREE MINDED CONSIDERATIONS ABOUT QUANTUM PHYSICS WITH ADOLFO BROCHETELLI

Dear Adolfo,

I have found delays of more than 133 ms theoretical in my long path measurements. Delays of about 5% more and in some cases even greater. In one case as much as 330 ms. Never less.
In your case the accounts do not seem to come back with much greater differences. I tried to explain them to myself by thinking of a longer path than the wave that travels not at ground height but higher in the ionosphere and in the magnetosphere. As you say, the magnetic field can deflect the wave and make it go further. There may also be a more "extreme" or "heretical" and more fascinating explanation, linked to quantum physics.
In 1900 Max Planck proposed the quantization of energy. The energy does not transfer in a continuous, but for discrete quantities, said how many. For electromagnetic waves, the energy of the various quantum depends on the wavelength of the associated radiation. I am wondering If quantum physics get involved.

Dear Flavio,
The quantum physics and in general of electrodynamics is my fixed ball. I am reviewing the last paper I sent you. Let us start from a stable point: The power emitted by Roma PT Radio on 8 MHz, which should have been about 10 kW on an antenna with much more gain dB compared to the isotropic antenna.
Over long distances such a power that really has a huge wavefront and given its relative "short" distance, one cannot apply Poynting's theorem, perhaps not even Faraday's.
If the wavefront hits ionized multilayers both from the point of view of the solar wind, from the atmospheric state crossed, and from ionization and the radio frequency wavefront, it impacts between the stratosphere and the magnetosphere and this can produce a duct. We can fall back into the field of multipath. Multipath therefore carries two types of fading. Positive fading (signal increase) and negative fading (signal decrease).

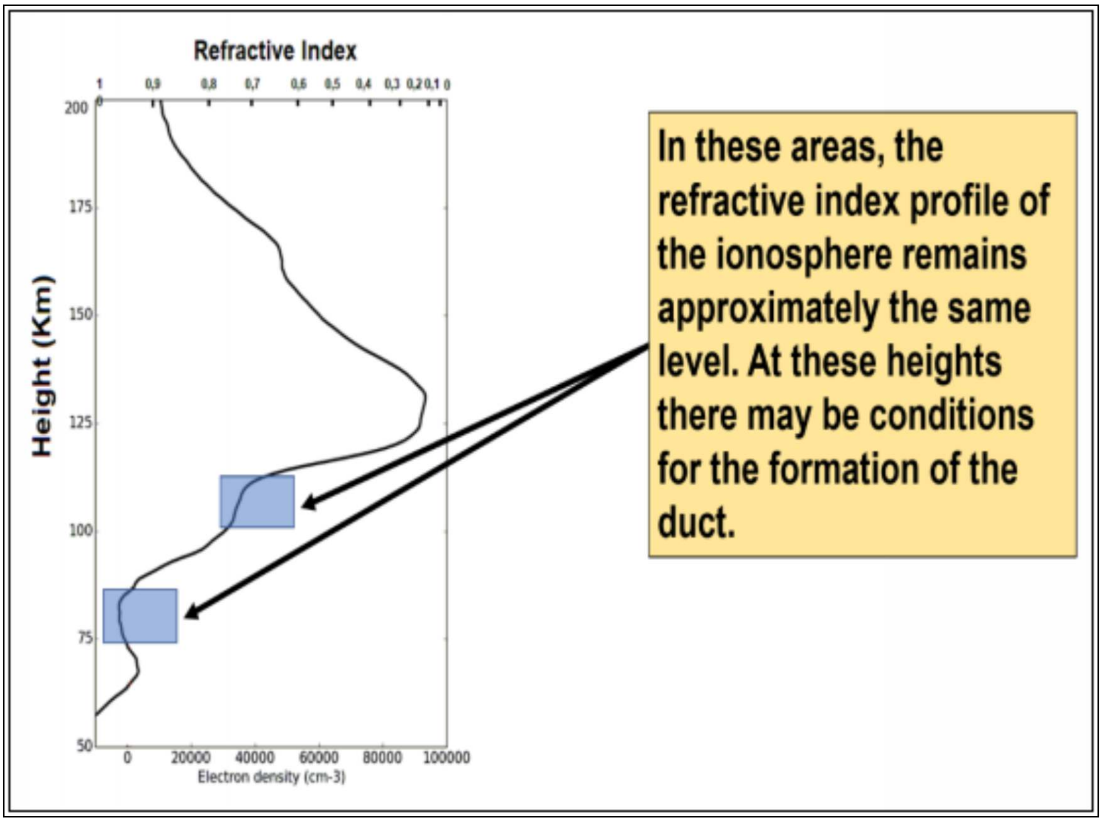
The second element is that the antenna used at that time by Roma PT Radio was not directional, this generates, wave beams at the highest energy level that propagate in different directions. Their typical phase shift is 180 degrees. Recombination on the receiving antenna on board the ship has the same recombinant and therefore overlapping effect. Some of these signals recombine due to the phase of lapse overlap for delay time giving shape to a point that becomes line. From the books in my possession "Electricity and Magnetism", part one and part two, by Edward Mills Purcell of Harvard University, (Nobel Prize in Physics in 1952), and referring to the basic electrodynamics of both Fermi and the latest authors, the clash of radio frequency (which is nothing more than light that "roasts" there are combinations between quantum elements.

But, realistically speaking, most scientists are inclined to multipath classics. I remember my DX with Australia in QRP, 3 watts of power, in June 2012, when I argued that the signal had passed from the north pole, having connected radio amateurs lined up from Atlantic coast of North America, from Atlantic to Pacific coast of Canada, California, Japan to the southern areas, where I begin to suspect that the famous ducts that form for short waves do not follow the right orthodromic path, but fall into a spiraling rhumhydromic circle. It must be said that on the day 7th of that month the earth was hit by a strong solar wind. So, ionization, as we know it, may have changed. Dear Flavio, problem is linked to only one factor: How many radio amateurs or former Navy radio telegraphers on board, or which telecommunications organization, can provide data, experience, and documents? It remains our own will, to give a deeper explanation than the classical one to which the various layers F, E, D, etc. have accustomed us. Today all telecommunications are via

satellite and the frequencies are rising more and more. One day, if amateur radio still exists, we will have all the HF frequencies, medium and long waves available. In those days, no one will want to have brain experiences anymore. Will it be enough to open the computer and find all the answers?

The mechanisms of duct formation and how the waves or come out

There is substantial evidence that waves can, under specific circumstances, propagate over long distances without returning to the ground at periodic intervals, a phenomenon akin to ionospheric hops. This implies that the wave travels between two ionospheric layers, resembling a channeled wave. For this to occur, the refractive index profile of the ionosphere needs to align. This alignment creates a duct at the level where the refractive index remains constant. However, a key question remains: How does energy manage to exit the duct? To address this question, I will refer to the graph below, which depicts a typical diurnal ionosphere profile. The top horizontal axis of the graph illustrates the refractive index, ranging from 1 to 0, while the bottom horizontal axis represents electron density, measured in Electrons per cubic centimeter. In the ionosphere, like any other medium, the velocity of a wave (or phase velocity) increases as the refractive index decreases. The formation of a duct becomes feasible if a region exists where the refractive index height relationship holds true. When the refractive index remains constant at a specific height, conditions for duct formation are favorable. If the refractive index remained constant throughout, waves would travel in a straight line. Conversely, if the refractive index gradient were excessively steep, the wave's trajectory would sharply bend, potentially exiting any duct. The precise mechanism governing the entry and exit of energy through the duct remains a subject of much debate. Although I lack mathematical certainties and still possess several doubts, I believe that the discontinuities in the refractive index are instrumental in enabling energy to enter and exit the duct. As previously mentioned, these discontinuities are notably present along the grey line.



Partial solar eclipse of January 4, 2011

Radio reception experiments on long waves 225 KHz Radio Poland

Introduction

To study the behavior of the ionosphere and especially the absorption of D region, I have tried to take advantage of a partial eclipse of the sun. The eclipse that occurs during the hours of the day, allows us to directly see the variation in the level of absorption before, during and after the eclipse. This is this simple experiment that we are going to analyze below.

GENERAL CIRCUMSTANCES OF THE ECLIPSE - Eclipse of the Sun, Partial of 04/01/2011

The eclipse will start at 06h40m23s U.T., the central phase will be at 08h50m31s UTC and the last contact will take place at 11h00m21s UTC. The maximum duration of partiality is 259.97 minutes.

The magnitude of the central phase of the eclipse is 0.858.

RADIO POLAND
225 kHz Radio
Power: 1200 kW Directional aerial, 2 guyed radio masts fed on the top, heights 330 m and 289 m
QTH: Bydgoszcz – Poland.

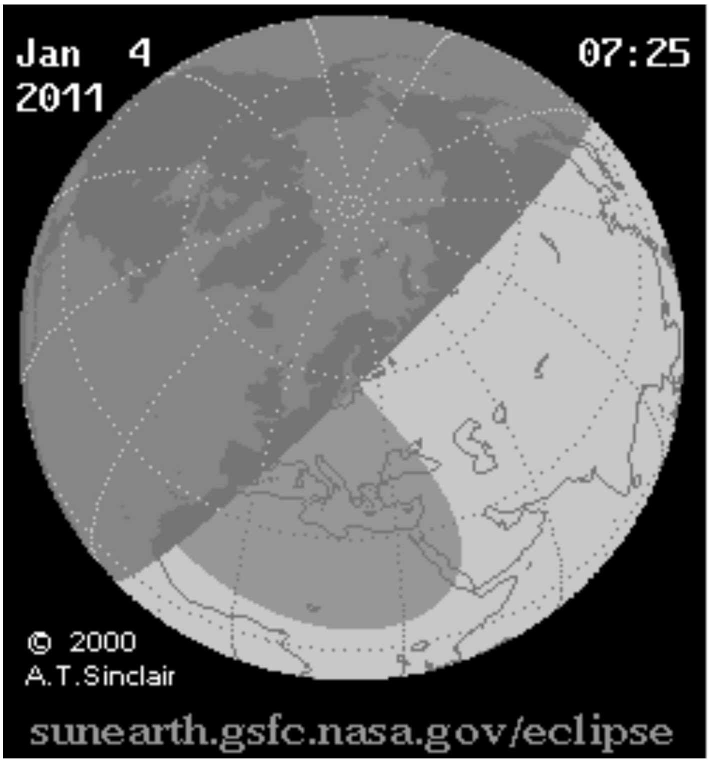
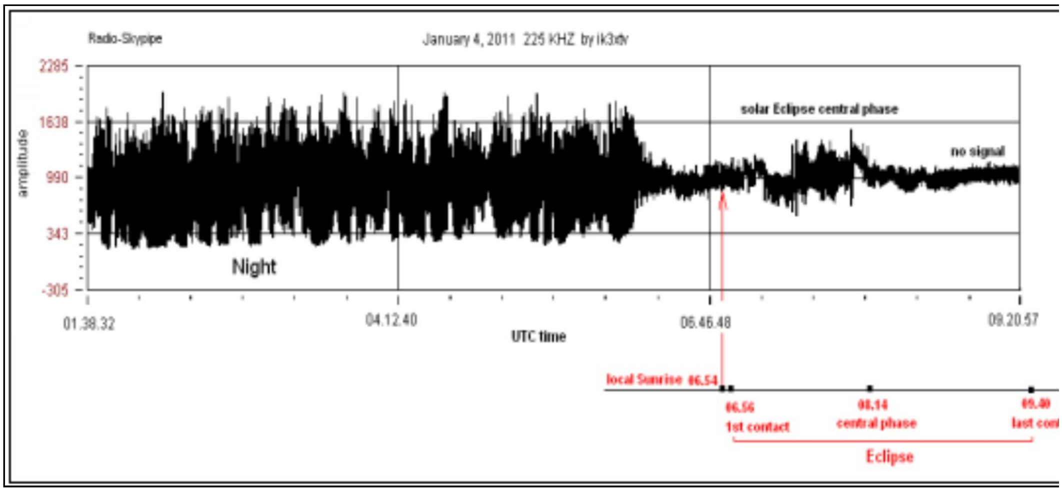


Image credits: Attribution: Eclipse Predictions by Fred Espenak, NASA's GSFC (from Wikipedia).

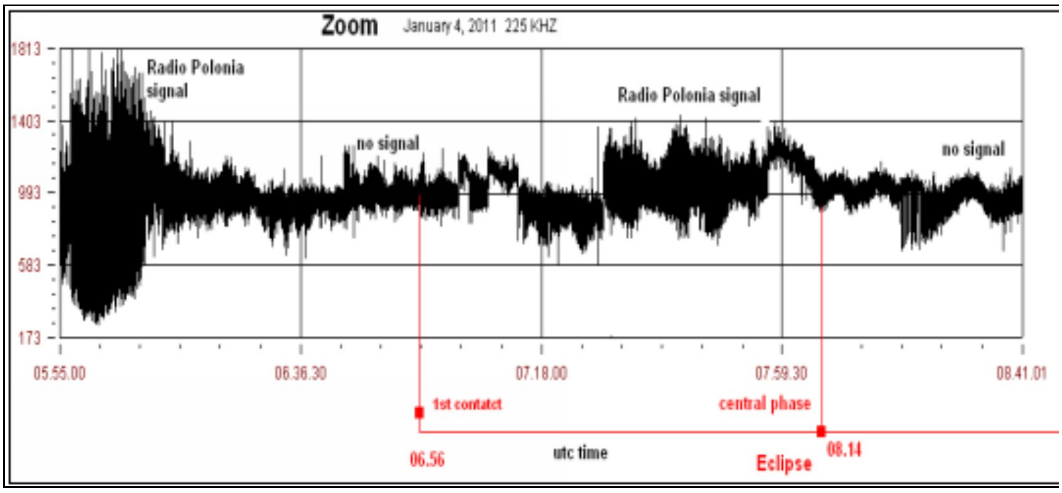
Long wave experiment

Radio Poland long wave signal on 225 KHz, stable reception throughout the night, progressive

reduction of signal strength just before the local sunrise of the sun (the sun first illuminates the ionospheric layers, D layer begins to be illuminated when the sun is at about -10 degrees, for this there should be a hysteresis effect), absence of signal or very weak signal with strong fading with significant increase in the central phase of the solar eclipse. The signal immediately after the central phase gradually disappeared.

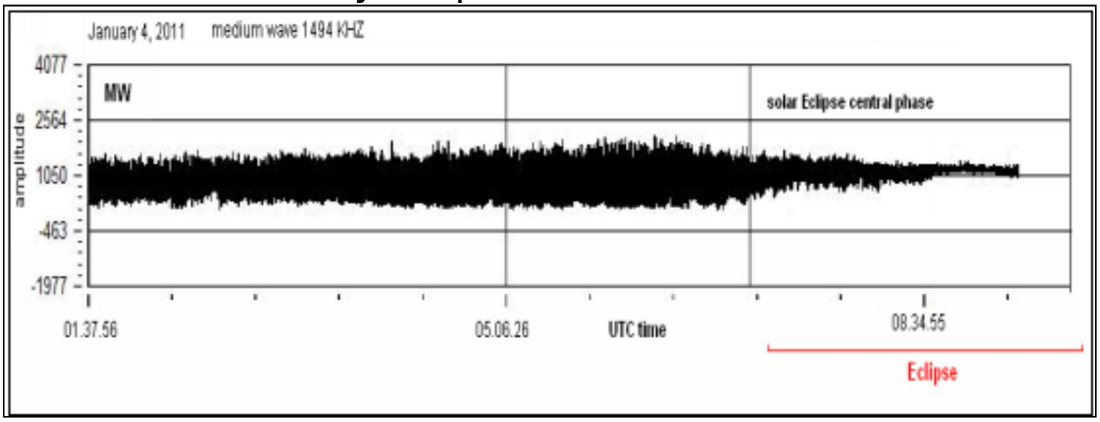


The graph below shows the zoom of the test in Long Wave where you can see the trend of the signal in detail. As for what has been said about the hysteresis of D layer, the same effect can also be seen on the influence of the eclipse as the peak signal anticipates by a few minutes the maximum phase of the eclipse linearly with what has been said about the fact that the D layer meets the radiation of the sun before the Earth's surface.

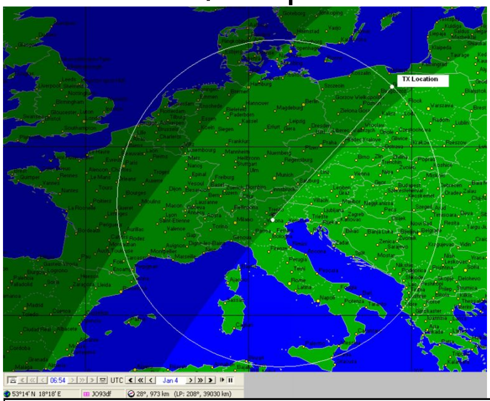


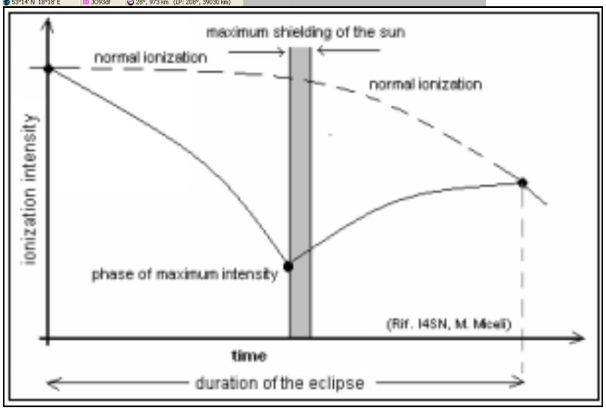
Medium wave experiment on 1494 KHz

Below is a medium wave test with 1494 KHz station monitoring
"Voice of Russia" from St. Petersburg. The test in medium waves did not detect significant effects of the partial eclipse of the sun, only a progressive reduction and then disappearance of the signal after sunrise, due to the absorption of D layer, no effect or any anomalies were detected causes by eclipse.



The map of Europe below, shows the footprint of the long waves experiment, the choice of station Radio Poland was made as it is aligned on the terminator with my QTH, to attenuate as much as possible any correlations / interferences due to the different position of the terminator/eclipse.





The graph on the other side (Ref. I4SN M. Miceli) represents the characteristic scheme of ionospheric ionization connected with the eclipse cycle. The lunar screen prevents solar radiation from reaching the layers of the Earth's ionosphere. Therefore, the ionization level decreases rapidly, decreasing progressively until it reaches the maximum negative peak near the point of maximum solar occultation. Then ionization grows rapidly until it reaches its normal level as lunar occultation decreases.

Map created using the DX Atlas software, www.dxatlas.com.

Variations

The electronic density varies from day to night. In the grey line, the ionosphere undergoes sudden changes. The ionosphere undergoes a drastic change of ionization in the transition from day to night. The electron and ion density in E layer decreases by a factor of 200 and by a factor of about 100 to 1 in F layer. After sunset, D layer quickly disappears.

D layer

D layer, extends, from 50 to 90 km, with an electronic concentration that grows rapidly with height. The electronic concentration in D layer shows an important daytime variation: it reaches its peak shortly after local solar noon, while it keeps extremely low values at night. In winter, even though the zenith distance from the sun is large, extremely high electronic concentrations are often observed, always between 70 and 90 km, due to the nature and concentration of the gases that make up the atmosphere. The influence of solar activity on the electronic concentration in D layer differs at different heights: between 70 and 90 km, solar X-rays are the main source of ionization and this is maximum when the solar cycle is at its peak; below 70 km the most active radiation is cosmic radiation and the maximum concentration occurs when solar activity is at its lowest, so the interplanetary dispersion of cosmic rays of galactic origin tends to decrease. During a geomagnetic disturbance, the electronic density between 75 and 90 km tends to strengthen at sub-auroral and lower latitudes, due to the supply of electrons with a high energy content. D layer can reach a maximum density of 10 billion electrons per cubic meter at altitudes between 50 and 90 km, with high neutral particle density. This layer is not, due to its low electron density, of significant importance for reflectivity regarding waves used in communications via the ionosphere, while it is of considerable importance about absorption, so much so that D layer can be considered the absorbent layer par excellence.

Considerations

The moon's occultation of the sun's corona shields ultraviolet radiation radiated towards the earth, so there is a sudden decrease in ionization found in the lower layers of the ionosphere (especially D and E layer) as they are the layers with higher molecular density. The low molecular density of the higher layers (F1 and F2) does not allow rapid recombination of free electrons with the consequence of the reduction of contribution of U.V. radiation, caused by the eclipse. It does not have a significant impact on the higher ionospheric regions. Because the shielding of the sun's corona is too short. Although it was only a partial eclipse, the strong reactivity of the ionosphere is showed, especially in D region, where the recombination processes in the day-night passage are extremely fast.

References:
The recordings were made with Radio skypipe software.

WSPR experiments in long waves on 474 KHz.

In this scenario, we find ourselves at a boundary frequency between long and medium waves. Officially, low frequency (LF) refers to radio frequencies in the range of 30–300 kHz, as designated by the ITU. Due to their wavelengths spanning from 10 to 1 km, this band is also recognized as the kilometer band or kilometer wave. LF radio waves exhibit minimal signal attenuation, making them well-suited for long-distance communications. In regions including Europe, parts of North Africa, and Asia, a portion of the LF spectrum is employed for AM transmissions as the 'long wave' band. Conversely, in the Western hemisphere, LF is primarily utilized for aircraft signaling, navigation, information, and weather systems. Additionally, several time signal transmissions make use of this frequency range. An important concept to note is that ground losses cause more significant attenuation as frequency increases. Owing to their lengthy wavelengths, low-frequency radio waves can diffract around obstacles like mountain ranges and continue beyond the horizon, following the Earth's curvature. The wave's speed is slightly diminished by the dielectric constant of the ground, causing a downward tilt of the wavefront. This effect enables signals to surmount the Earth's curvature and extend beyond the typical visible horizon. This mode of propagation, termed 'ground wave,' prevails in the LF band. To accommodate ground waves, vertical unipolar antennas are used for transmission, necessitating vertical polarization of the electric field and horizontal polarization of the magnetic field. Notably, signal strength attenuation due to ground absorption is lower compared to higher frequencies, enabling the reception of low-frequency ground waves up to approximately 2,000 kilometers from the transmitting antenna. Occasionally, low-frequency waves can achieve long-distance travel through

ionospheric reflection, a mechanism akin to refraction. This phenomenon, referred to as 'space wave,' is less effective than in the case of short waves. In simplified terms, during the day, long waves propagate via the ground wave, while at night, in the absence of the D region, they are reflected by the E region of the ionosphere. The propagation of very low-frequency (LF) radio waves through the Earth-Ionosphere waveguide is highly contingent on the plasma properties of the ionospheric D layer. Solar ultraviolet radiation significantly influences the physical and chemical characteristics of the lower ionospheric layers, thereby impacting LF signal propagation. The interplay between different propagation modes ground wave and space wave varies extensively based on propagation path length. For extended paths, solar radiation exposure and subsequent ionization alterations along the route modulate the behavior of LF sky wave propagation. To comprehend the intricate propagation characteristics over such extended distances, comprehensive investigations into the chemical reactions of the lower ionosphere and an in-depth analysis of diverse propagation paths are imperative.

Effect of frequency on ground wave propagation
When the wavefront of the ground wave travels along the Earth's surface, it is attenuated. The degree of attenuation depends on a variety of factors. The frequency of the radio signal is one of the main determining factors since the losses increase with increasing frequency. As a result, it makes this form of propagation impractical above the lower end of the HF part of the spectrum (3 MHz). Typically, a 3.0 MHz signal will undergo attenuation that can be 20 to 60 dB more than one at 0.5 MHz and depends on a variety of factors in the signal path including distance. Therefore, even high-powered HF radio stations can only be heard for a few kilometers from the transmission site via the ground wave. This study, done with WSPR reports, is particularly important because it allows us to see up close the behavior of the ionosphere

and the behavior of D layer. Studying these frequencies is like pointing a lens over ionospheric D layer.

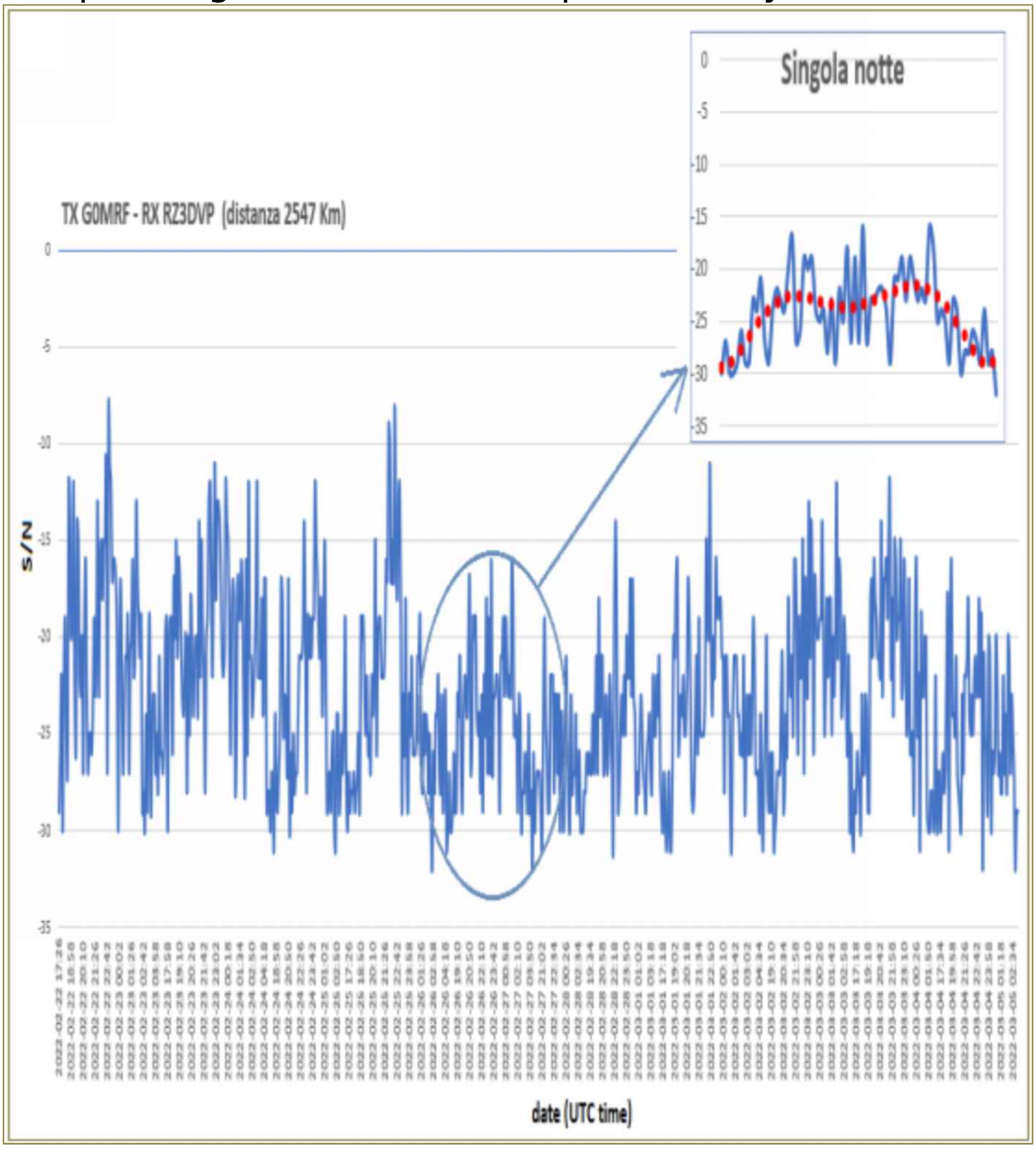
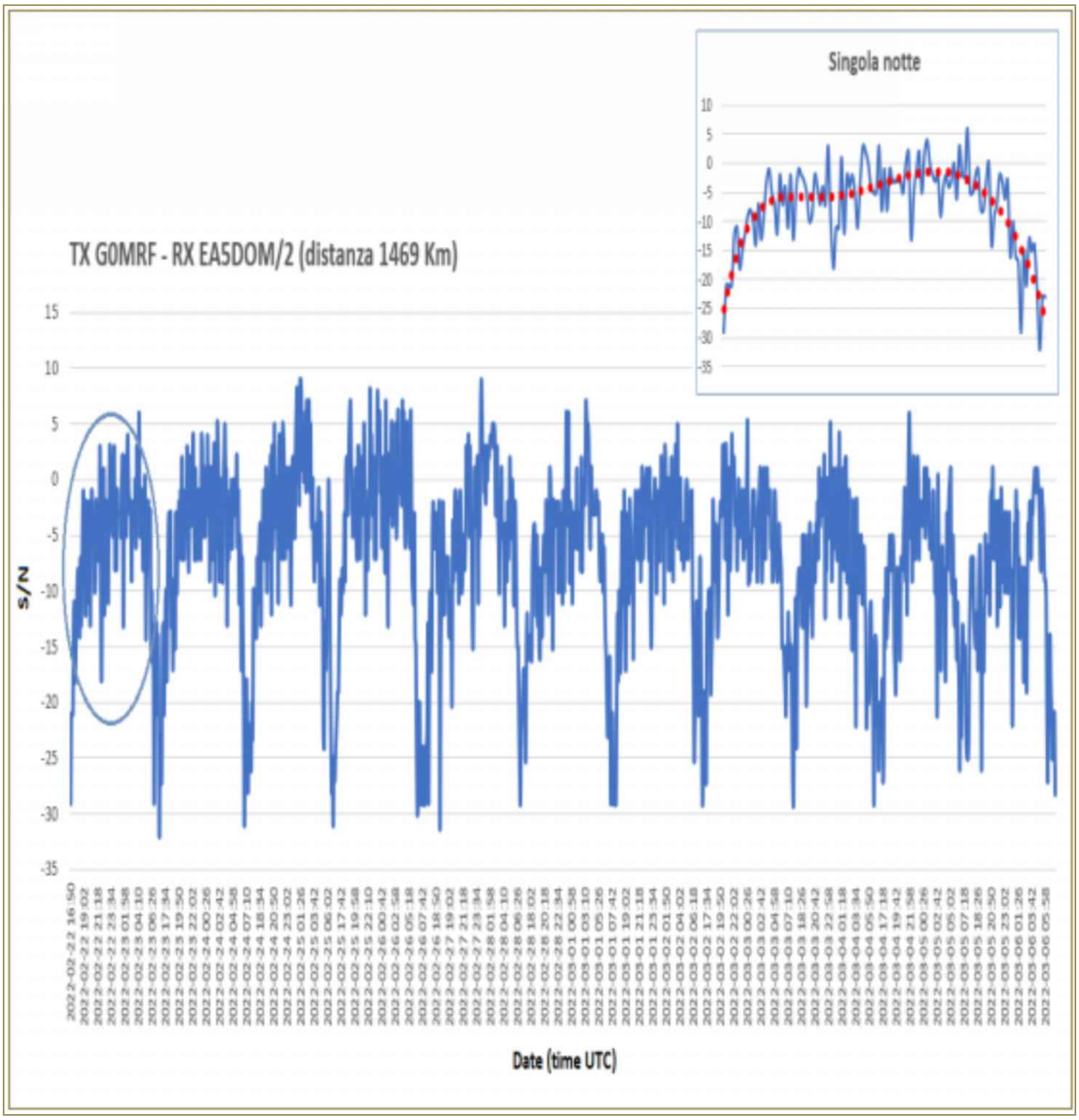


Fig. Long waves propagation (474 KHz) for a very long path. This is 2537 kilometers propagation path between UK and Russia. We noticed the path is open only during the night. During the hours illuminated by the sun, the propagation is completely closed. The propagation of the wave occurs exclusively by ionospheric refraction as the ground wave cannot cover such long distances. In the upper right window, the signal trend in a single night is shown. Note the significant signal instability (S/N), due to the congenital instability of the ionosphere.



TX G0MRF - RX EA5DOM/2 (distanza 1469 Km)
Singola notte
S/N
Date (time UTC)

Fig. Long waves propagation (474 KHz) for a long path This propagation path is 1469 kilometers between UK and Spain. The propagation is open only during the night. The shorter distance shows greater stability in the central hours of the night. The propagation tends to stabilize just few hours after sunset until a few hours before sunrise. We must also consider that the power transmitted with the WSPR signals is extremely low. G0MRF, transmits in WSPR mode with a power of only 5 watts.

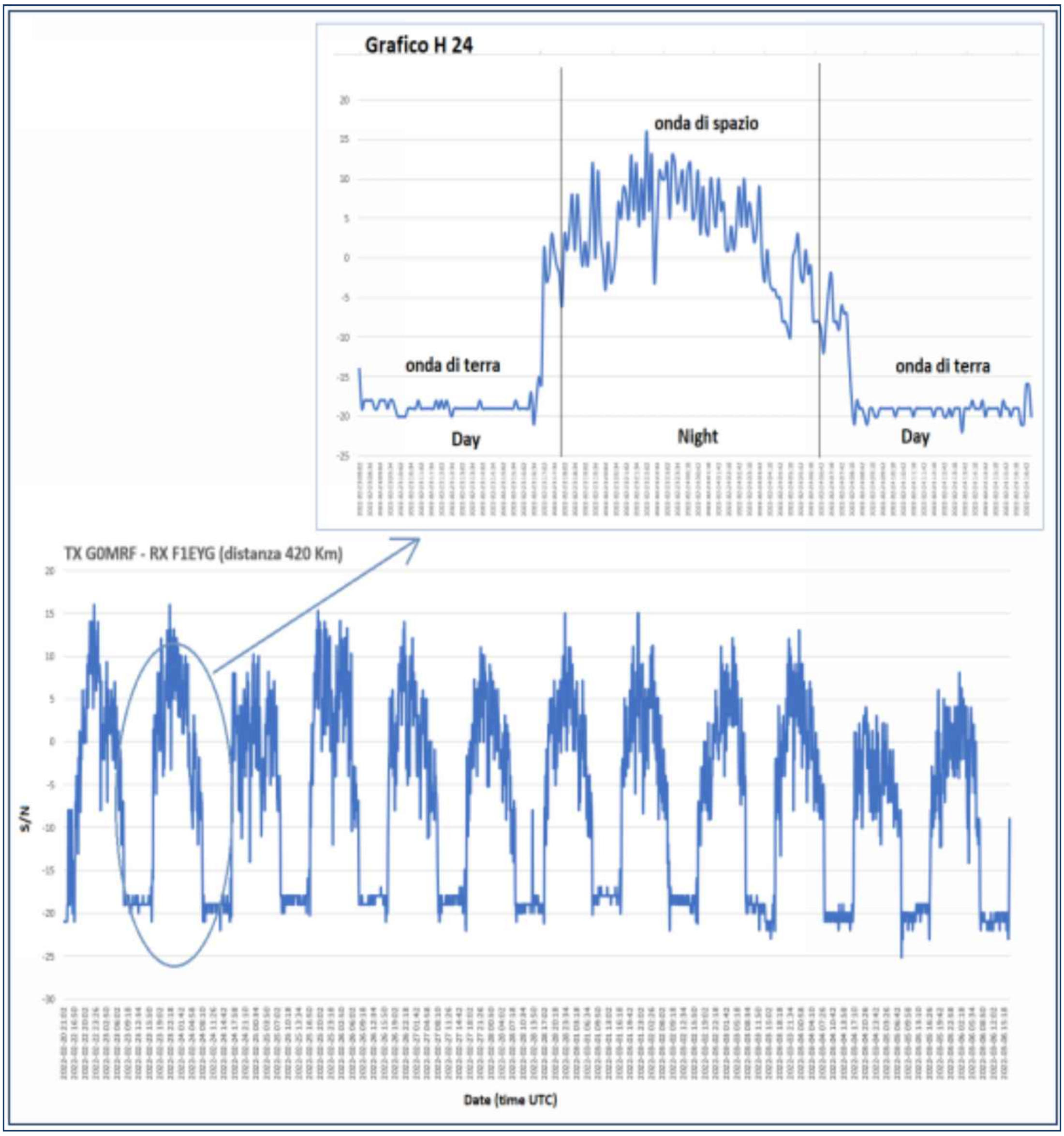
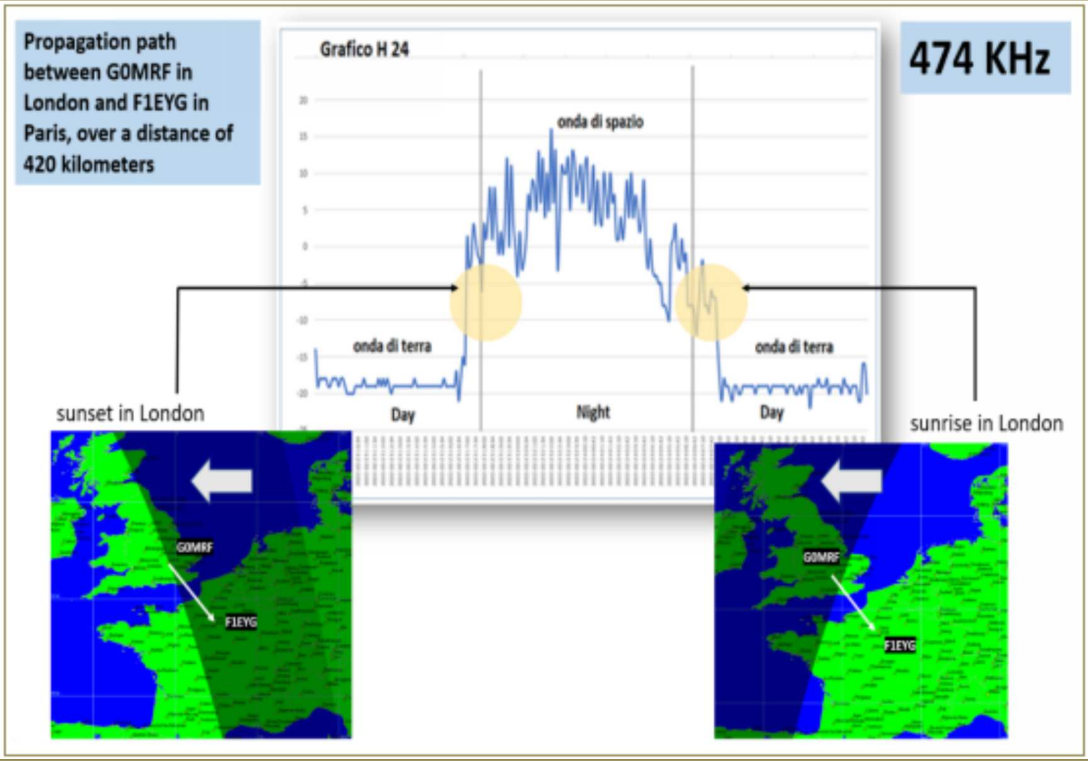
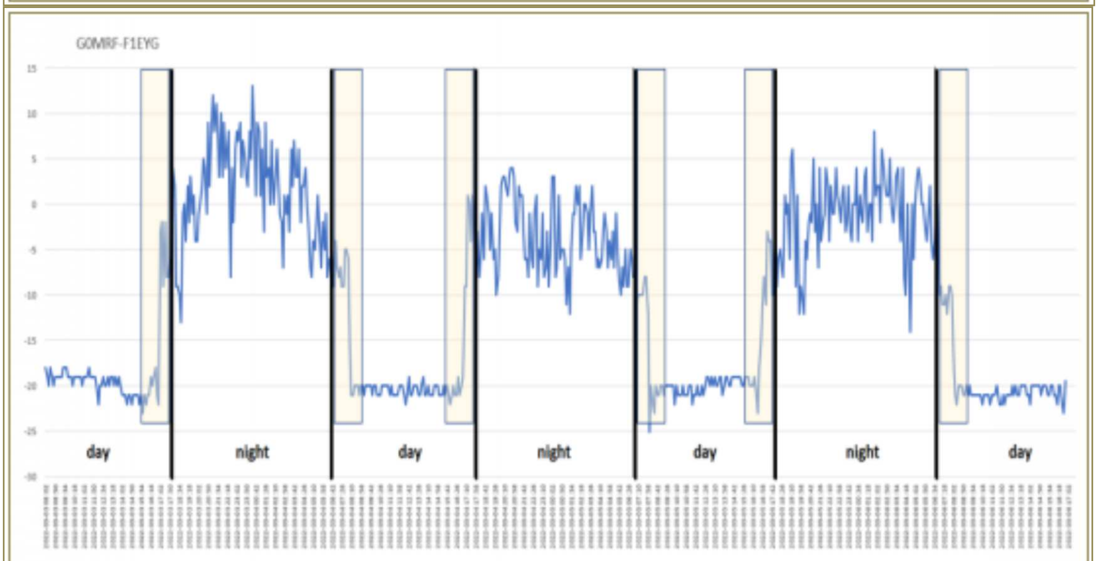


Grafico H 24
onda di spazio
onda di terra
onda di terra
Day
Night
Day
TX G0MRF - RX F1EYG (distanza 420 Km)
S/N
Date (time UTC)

Fig. Long waves propagation (474 KHz) for a short path, between G0MRF in London and F1EYG in Paris, over 420 kilometers. In this case we see the presence of a propagation by ionospheric wave at night and by ground wave during the day. Note the great stability of ground wave signal compared to space wave signal, as evidenced in the right window inside the graph, where the signal trend for 24 consecutive hours is reported. In Paris and London, the sunrise and sunset are about at the same time. There are only a few minutes of difference. The vertical lines in the graph at the top right show the time of sunset and sunrise. A remarkably interesting thing is the hysteresis before sunset that is repeated symmetrically after dawn, in conjunction with the grey line. In addition,

ionospheric propagation is much more effective, with an average difference of +30 dB.





By analyzing several days of G0MRF-F1EYG WSPR report, the hysteresis before sunset and after sunrise always occurs. It is repetitive.

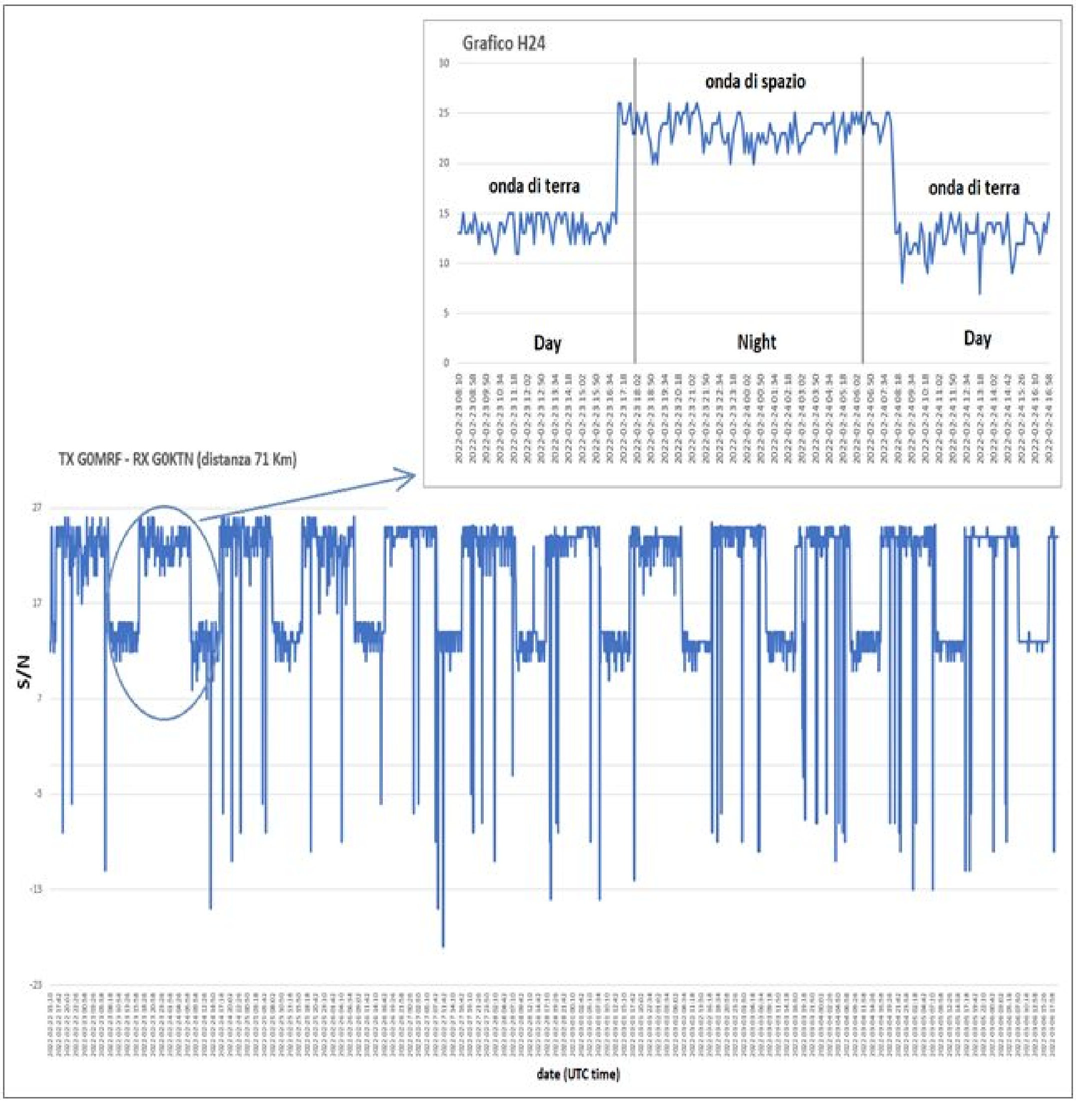


Fig. Long waves propagation (474 KHz) for a very short path, between G0MRF and G0KTN, over only 71 kilometers. We can see the presence of ionospheric wave at night and ground wave during the day. There is high signal stability, both by ground wave and by space wave. We always see hysteresis before sunset and after sunrise.

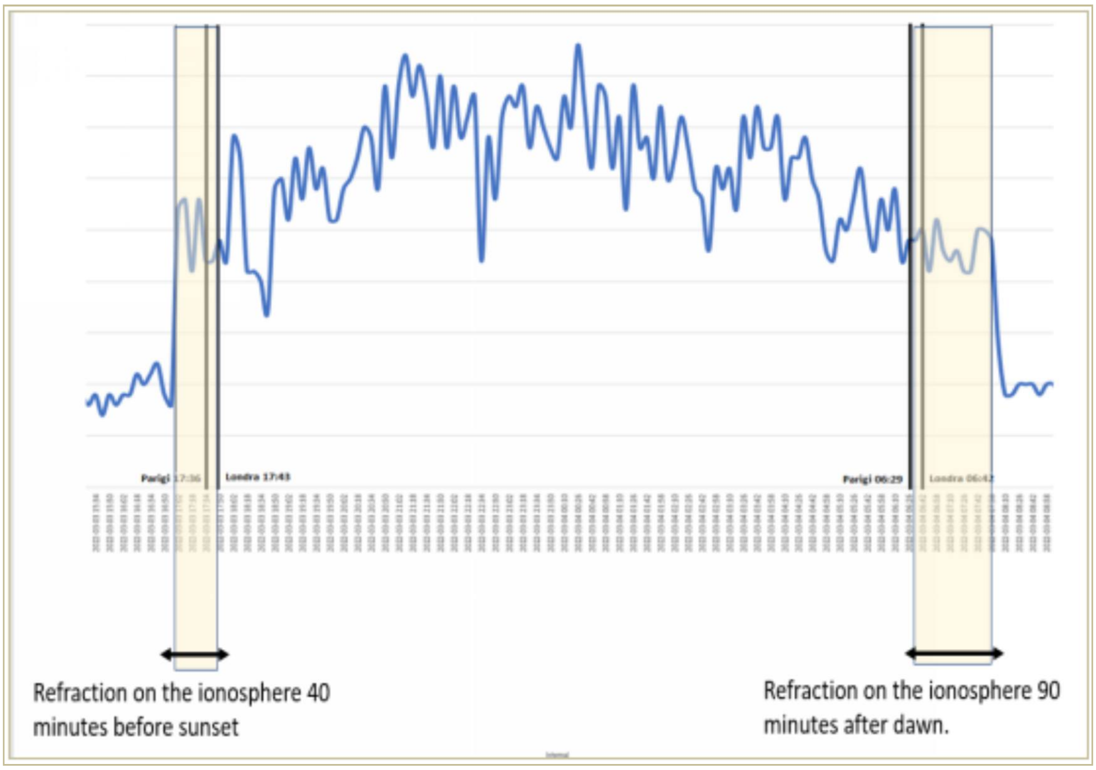
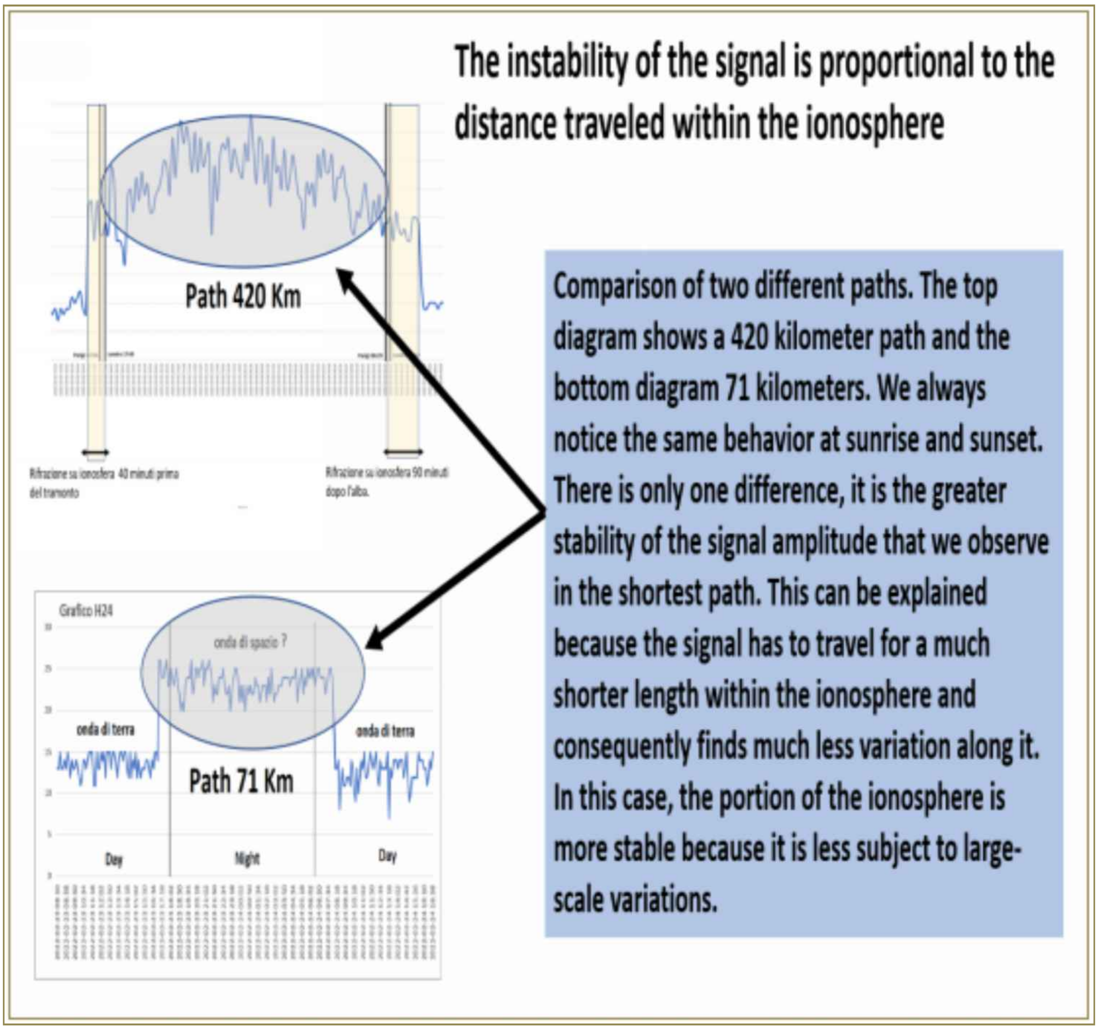


Fig. Detailed measurements of hysteresis before sunset and after sunrise. The persistence of the space wave after dawn is much longer.

An attempt to explain hysteresis

As we have already said, the study of medium and long waves is interesting because it allows us to observe very closely the behavior of the ionospheric layers, especially near the grey line. The ionospheric layers involved in medium and long waves are layer D, E and F, at heights of the order of 85, 110 and 300 km, respectively. When a signal encounter one of these layers, some of the signal energy is absorbed by the layer, part is dispersed through the layer, and the rest is reflected. During daylight hours, the lowest layer (D layer), reflects a negligible minimum of incident signal quantity, and therefore the ground wave is predominant. At sunset, the ionization of the layers begins to decrease, and D layer quickly disappears. So, the first layer reached by signals is the E layer, and its ionization is sufficient for a period after sunset such as to guarantee refractions anyway. The duration of this period is a function of the frequency of the signal and the angle at which it hits the layer. In long waves and even in medium waves, the signals penetrate the E layer and continue towards the F layer, where another refraction occurs. These signals are, however, attenuated by passing two time through the lower layers, but this is another topic and will not be discussed here. At dawn, the ionization of the layers increases, and the D layer is reformed, and the reflections become negligible. The ionization of the E region decreases after sunset and this affects the conditions of reflection. The reflective layer is in a continuous state of change in both height and density with the consequence that the amplitude of the reflected signal is changeable.



Considerations

Why is it interesting to study these frequencies? Because the analytical study of medium and long waves, allows us to understand how the ionosphere behaves and how it behaves on the famous grey line, the Holy Grail of radio amateurs.

- D Layer has a different behavior between sunrise and sunset.
- The density of D layer begins to decrease already several tens of minutes before sunset.
- The density of D layer persists even after sunrise, with longer times than the decrease time before sunset.

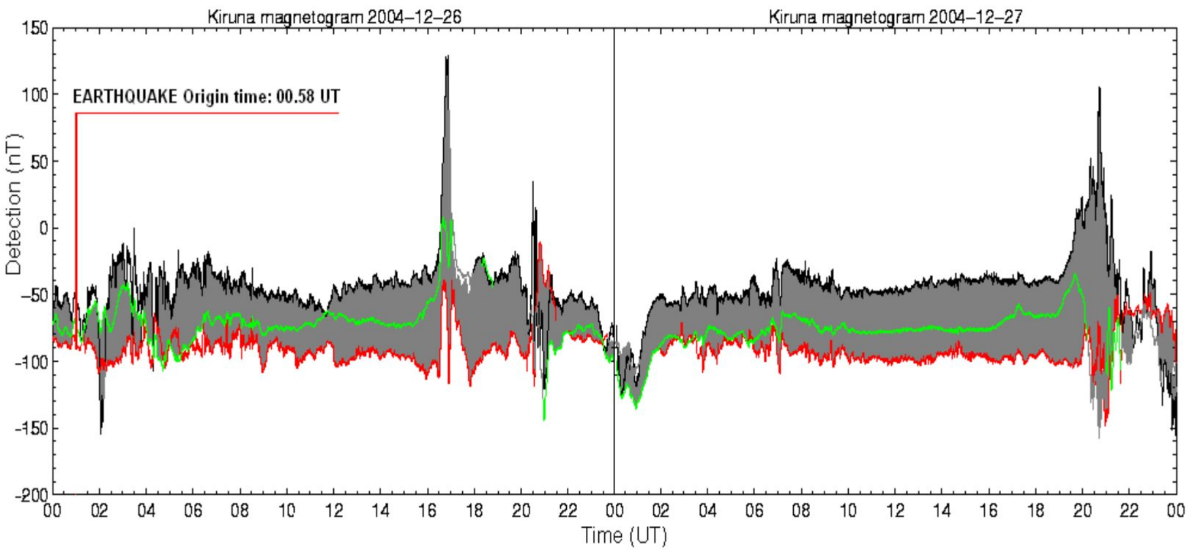
- The amplitude of the signal has a Gaussian trend, during the night, when the distance between the stations is greater than a few hundred kilometers.

The effects of seismic waves on the Ionosphere

The Indian Ocean and Indo-Asian Plate tsunami of December 26, 2004 was one of the most catastrophic

natural disasters of modern times and caused hundreds of thousands of deaths. It had its origin and development within a few hours in a large area of the Earth: it affected the entire south-east of Asia, reaching the coasts of East Africa, which together with the considerable number of victims, aroused a considerable impression among the media and in public opinion in the world. The event began at 07:58:53 UTC+7 (00:58:53 UTC) on December 26, 2004, when a violent earthquake, with a magnitude of 9.1, struck the Indian Ocean off the northwest coast of Sumatra, Indonesia. The earthquake lasted 8 minutes. (Source Wikipedia).

This research aims to verify the possible correlations between ionospheric propagation and a geophysical event such as the earthquake. I went to see if this exceptional event had any implication on the Ionosphere and the Earth's magnetic field.



Influence of the earthquake on the Earth's geomagnetic field

First, I have checked the geophysical indices immediately after the earthquake and in the following days to look for a influence on the Earth's geomagnetic field and therefore indirectly on the quality of propagation.

*Image courtesy of Swedish Institute of Space Physics**.** Magnetometer web**:*
*https://www2.irf.se/Observatory/?link=Magnetometers***.***

The checks conducted do not appear to have any obvious influence. The K index has remained consistently low, never above three and therefore calm, as can be deduced from the graph of NOAA/ SEC Boulder in Colorado –USA. However, this is the Kp index, i.e., the planetary index. So globally, the strong Earthquake in Sumatra seems to have had no impact on a global scale. Unfortunately, the lack of magnetometers and geophysical observatories on the area directly affected by the earthquake does not allow to have local data, the Earth's magnetic field in fact, can show localized changes due to efforts in rocks and movements in the crust. However, it is already interesting to be able to establish that even an event of this intensity (magnitude nine of the Richter scale) capable of modifying the inclination of the Earth's axis of rotation does not clearly change the Earth's magnetic field. However, a question is still open as well as a possible starting point for a more complete and in-depth research: the hypothesis is discussed in the figures below, where a trace of a possible seismic precursor appears, for this purpose it would be interesting to have a real-time detection of the geomagnetic variations recorded around the epicenter.

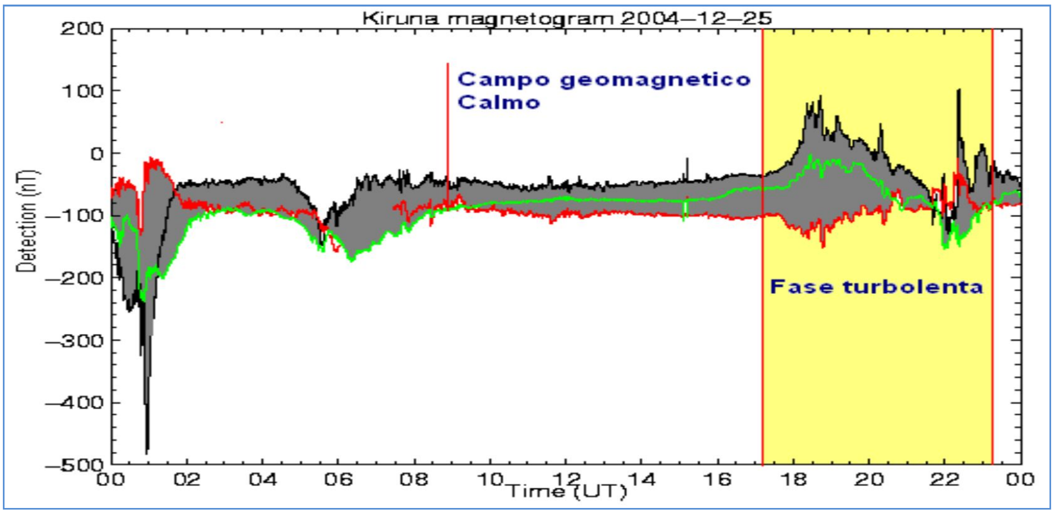
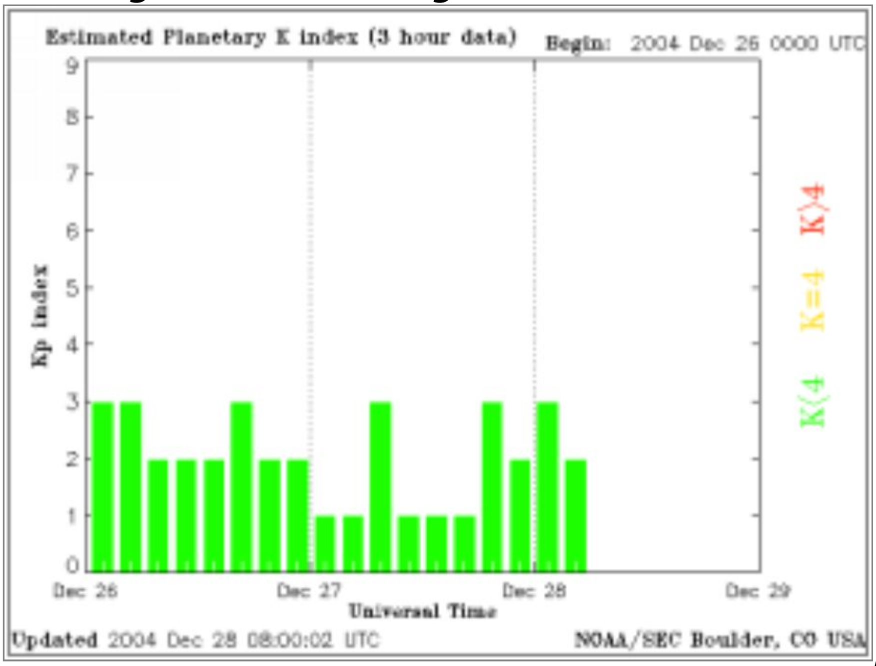


Fig. The graphs are interesting because they show the trend of the geomagnetic field recorded by the Kiruna magnetometer – Sweden from 25/12 until the whole of 27/12 and from which there are no strong geomagnetic

anomalies related to the southeast Asian earthquake, although there is a slight turbulent



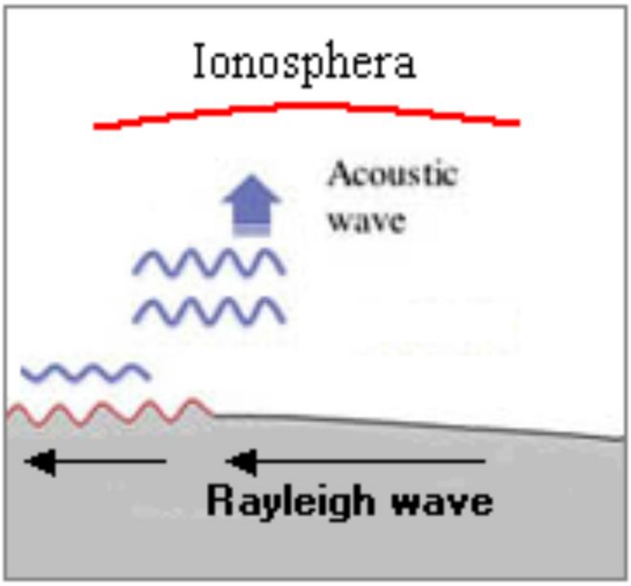
phase a few hours before the earthquake, followed by a quiet phase and then another phase of slight turbulence from 02:00 UT and for the following 2/3 hours, it is a slight anomaly and from the data currently in my possession it is not possible to establish a certain correlation with the earthquake. Image courtesy of Swedish Institute of Space Physics. Magnetometer web link: https://www2.irf.se/Observatory/?link=Magnetometers.

Fig. Trend of the Kp planetary index that remains at low values from 26 to 28/12.

The geophysical indices recorded on 26/12/04, on the other hand, are as follows:

Sunspots: 11 as of 12/27/2004: Flux: 97 | Ap: 7 | Kp: 2 (11 nT) Solar Wind: 439 km/s at 1.1 protons/cm3.

Image: Noaa Space Weather Prediction Center. (Public domain).



Disturbances in the Ionosphere Through the GPS detection network of the TEC electronic content of the Ionosphere, which collected the data immediately after the earthquake. It turned out that seismic waves triggered atmospheric disturbances near the sea surface, which moved upwards at an average speed of about 730 m/s (2700 km/h) and significantly disturbed the electronic density of the Ionosphere. So, the electron content in the ionosphere is also affected by an earthquake of this intensity. the Ionosphere in the area above the epicenter, undergoes considerable excursions in the total electronic content TEC. Acoustic waves propagate to F region and they are caused by a piston motion of the Earth's surface. These experiments have therefore confirmed that ionospheric perturbations can occur after an earthquake because of dynamic coupling between surface seismic waves and the atmosphere.

Fig. Rayleigh surface waves generate crustal movements capable of generating acoustic waves propagating towards the Ionosphere, causing ionospheric disturbances whose effect is not yet entirely clear but which in any case could generate abnormal disturbances and absorptions.

Conclusion

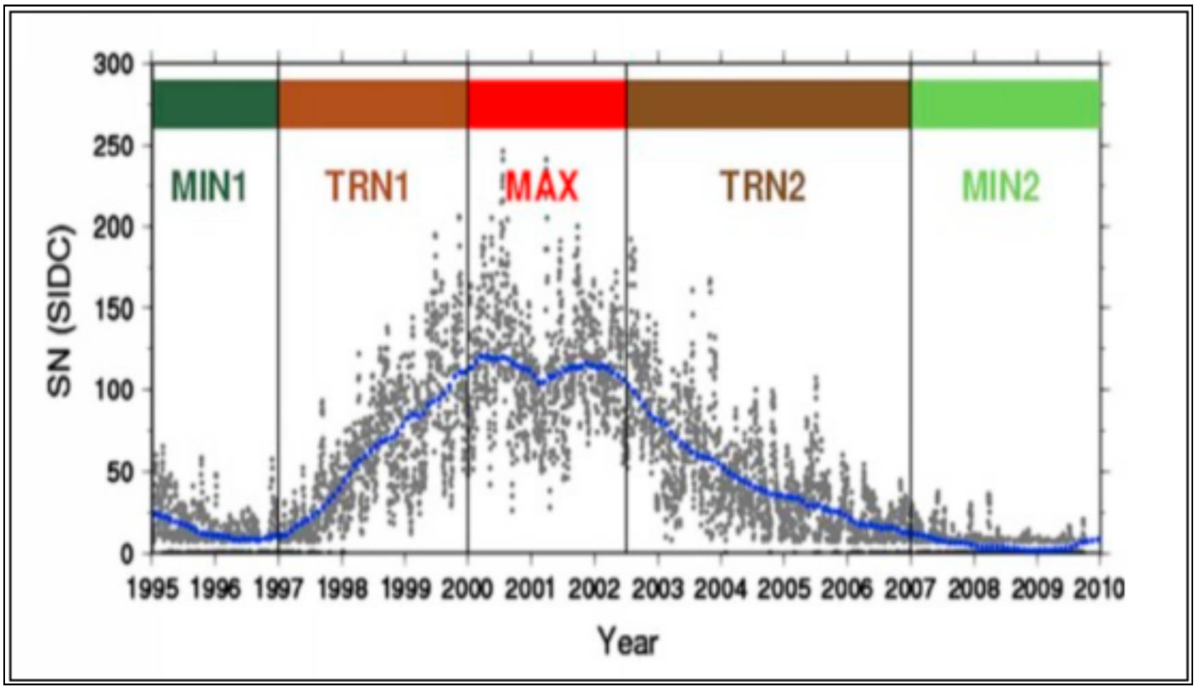
In this research I collected the geomagnetic data before and after the strong earthquake in Asia, to analyze from

another point of view the scientific development of the phenomenon, investigate the possible repercussions on radio propagation and discover any seismic precursors.
A geomagnetic anomaly was found just before the seismic event, followed by a short quiet phase (about 1 hour before and 1 hour later) and another turbulent phase. However, it is quite difficult to determine from the data collected whether these events are related to lithospheric phenomena, but it cannot be excluded they were generated by pre-seismic effects. More comprehensive and extensive observation of events is needed, which is currently difficult given the uneven geographical distribution of geomagnetic observatories, and it would also be interesting to support monitoring via a network of receivers tuned to the LF band to record any abnormal signals. So, I can say that there is no considerable evidence of magnetic variations, while it is established that earthquakes generate disturbances that affect the electronic content.

HF propagation and TEC

In this paragraph I would like to talk about a model for understanding the connection between TEC and the quality of HF ionospheric propagation. I compared the daily forecast of the total ionospheric electron content (TEC) to a given latitude. To develop model, I took as a reference 15 years. The data on TEC global and based on GNSS and solar indices (Sunspot Number, F10.7 and F10.7P derivative) including the 23rd solar cycle. For simplification, we can say that the conductivity of the ionosphere and consequently the quality of ionospheric propagation is directly proportional to the TEC, in the same way that the propagation follows the evolution of the solar cycle.

TEC definition



Although this is a parameter that we have already encountered several times, I remember the definition of TEC (Total Electron Content). We know that it is an important descriptive parameter of the Earth's ionosphere. Represents the total number of electrons along a path between two points, measured in units of electrons per square meter, with 1 TEC unit (TECU) = 1016 electrons/m2. TEC is essential for determining the scintillation and group delay of an electromagnetic wave passing through a medium. For the measurement of TEC, GPS satellites are used, with the technique of radio occultation.

Fig. Solar cycle 23. Number of sunspots (SN) provided by the SIDC grey dots: Daily SN; The continuous curve represents the average of the monthly sunspots. The colored rectangles at the top correspond to the different phases of activity of the Sun considered: MIN1 and MIN2 for the two minimum phases of activity; TRN1 and TRN2 for the two phases of transition activities; MAX for the maximum activity phase.

Considerations

TEC depends on several parameters: local time, season, geomagnetic latitude, solar activity. TEC varies significantly in both space and time and. In addition, the ionosphere is turbulent and prone to disturbances affecting TEC. We must therefore accept models and different approximations.

TEC variations

TEC's daily values have a high that often produces one hour after solar noon, usually between 1 pm and 3 pm local time. We can have another peak after dark. The minimum TEC always occurs just before sunrise. We have already seen that there is a negative spike before dawn. The TEC values also have a seasonal variation according to the months of the year. In the northern hemisphere there is a trend with a minimum in summer and a maximum instead both equinox and winter. The average TEC values can be 2.3 times higher in winter than in summer. The TEC also varies according to solar activity, characterized by the average periodicity of about 11 years. An example of these variations is summarized in the following figure.

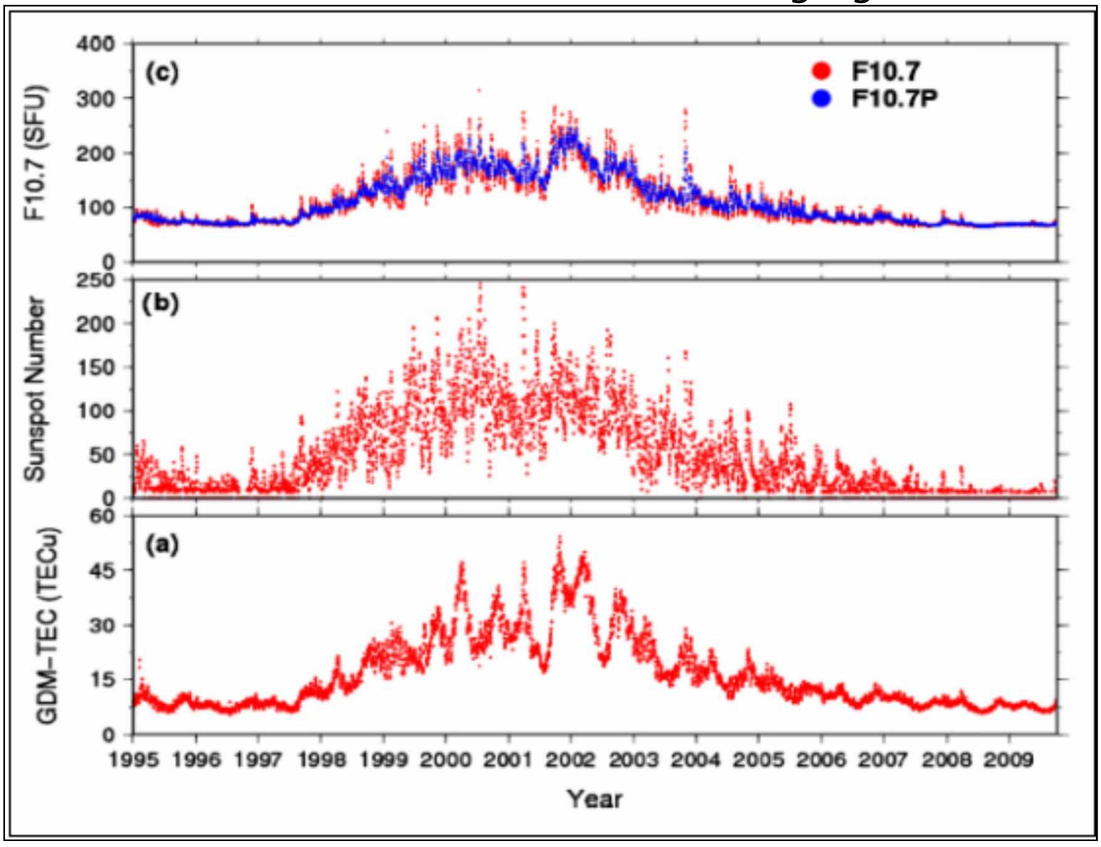


Fig. Ionospheric and solar data during the 23rd solar cycle. (a) Average global daily content of total electrons (GDM-VTEC) in TECu extracted from TM CODE. (b) Sunspot number delivered by SIDC. (c) Daily flux F10.7 from Penticton radio telescope observations (red) and derivative F10.7P (blue).

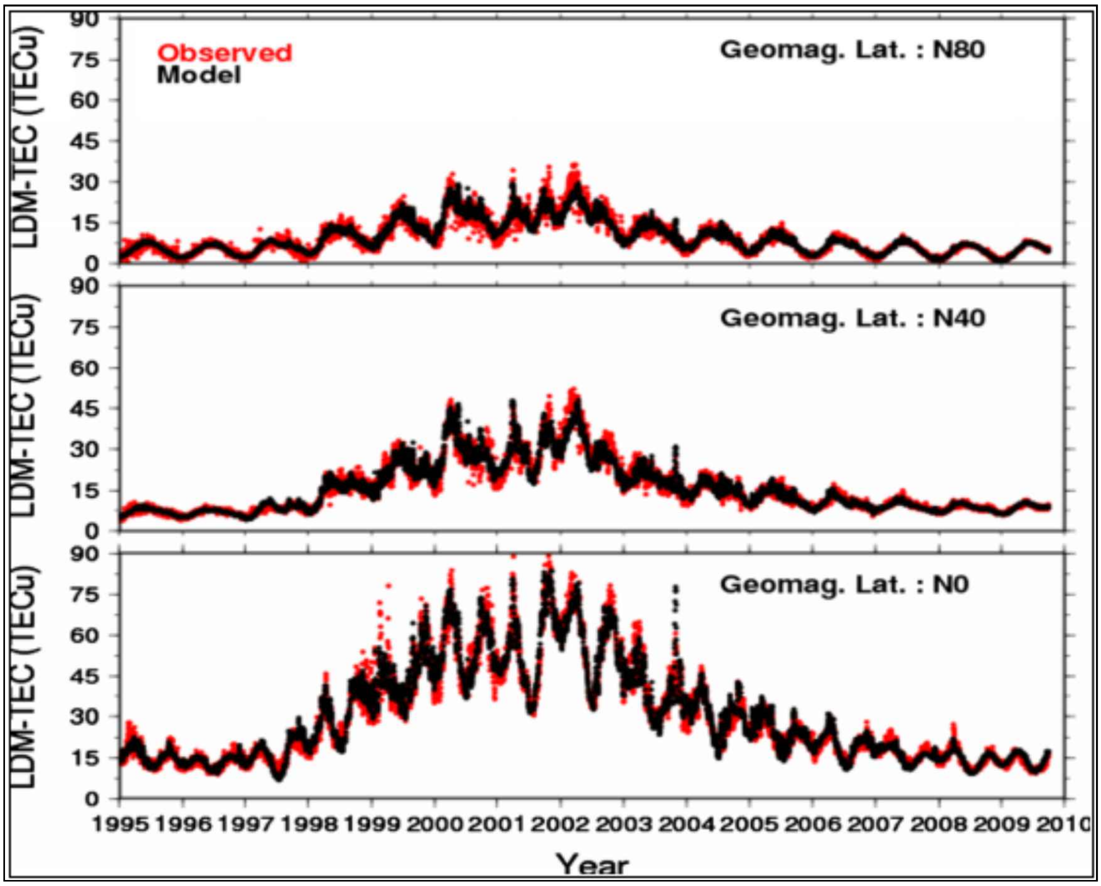
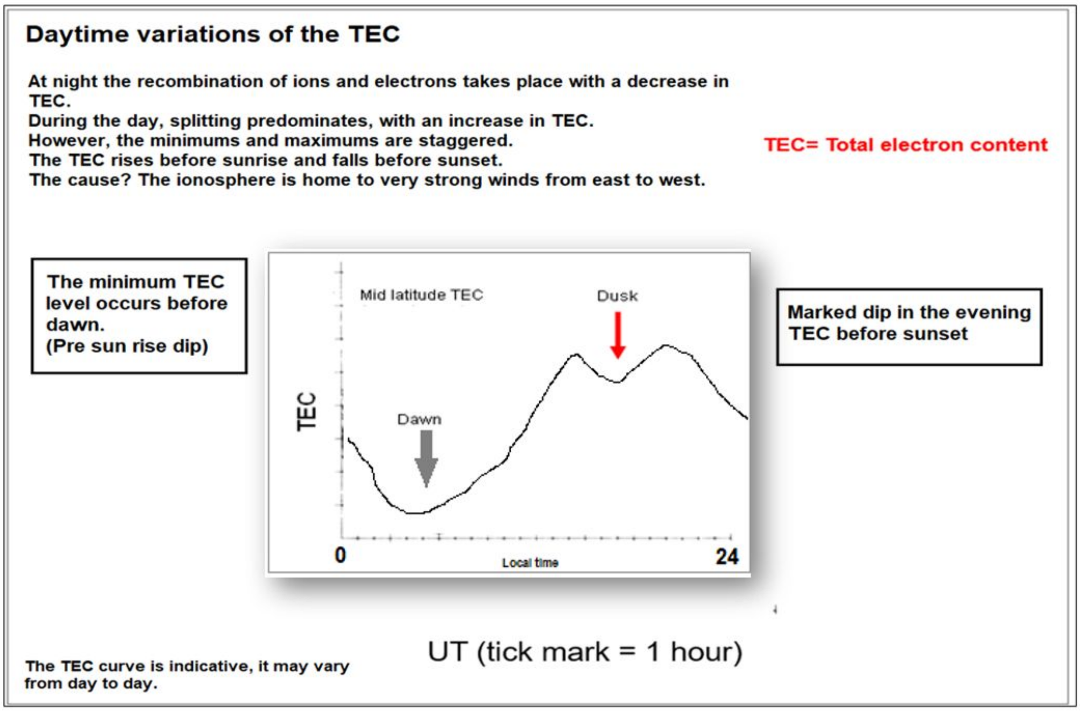


Fig. LDM-TEC (Latitude Daily Average TEC Values) modeled (in black) and observed (in red) for different geomagnetic latitudes. Bottom: geomagnetic equator. At the Centre: mid-latitude region. Top: Polar region.

Ionospheric refraction depends on the electrons

As we have already seen, when an electromagnetic wave enters the ionosphere, the electric field of the wave produces a displacement of electrons and ions; the displacement of ions is much more limited than electrons, because electrons weigh much less than ions, (about 2000 times less in the case of hydrogen, the lighter gas), so let us just consider the movement of electrons. Using the Altar Appleton equation describing the refractive index for the propagation of electromagnetic waves in a magnetized plasma, we deduce that the refractive index is proportional to the density of free electrons expressed with N. The wave is refracted because the collisions with free electrons.



Earth Moon Earth propagation (EME)

This section is dedicated to Earth-Moon-Earth (EME) communications, also known as Moon bounce. It is a radio communication technique that relies on the propagation of radio waves emitted by a transmitter on Earth, directed towards the Moon. Through reflection on the lunar surface, these waves return to the receiver. In the following pages, I analyze the challenges and intricacies of this technique, which is one of the most extreme and captivating aspects of amateur radio.

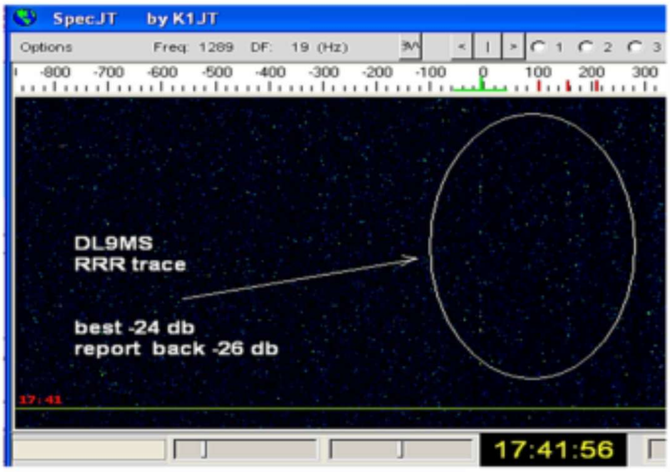
Research into the issues related to this mode of transmission has been meticulously conducted by Flavio Egano, IK3XTV, and Giorgio Marchi, IK1UWL. Their efforts include experiments and dedicated studies.

My first EME QSO

Man has always been fascinated by the moon, since prehistoric times. The "Blanchard Bone" dating back to about 30,000 years ago, has 69 engravings arranged in a spiral on the surface. They are engravings that rudimentary recall the phases of the Moon over two and a quarter month. The archaic peoples had a deep knowledge about the movement of our satellite. That lady who dominates the skies has always exerted a great fascination on me too. The night of the first of the year 2010, everything is ready. It is a full moon night. Beautiful and bright, in the clear January sky. Moon is at the Perigee, which is the closest point to the Earth. Our dear old Moon is "only" 358,696 kilometers away. Cosmic noise conditions are optimal. The sky is clear. In other words, there are the best conditions to do EME. I sit down in front of my radio, my computer and a cup of coffee. *"I had a good cup of hot coffee with me,"* Michael Collins said, when he was orbiting alone on the dark side of the moon during the Apollo 11 mission. I check on the EME chat and I see the post of the German station DL9MS, Joachim, who from the far north of Germany, almost 1000 kilometers away, calling CQ EME. I point the antenna carefully and tune the receiver to the calling frequency and I start to listen. The moon is rise and well visible above the horizon, but nothing. I have not any signals. But the EME requires a lot of patience. “Mister Faraday is always lurking.” The minutes pass quickly. The Moon continues its perennial motion. Other minutes pass, everything is silent, the screen shows no trace, only some disturbance. In the meantime, I continue to keep an eye on the elevation of the Moon, which slowly continues to rise. But suddenly, the first echoes begin to appear on my computer screen. An incredibly clear first trace, which is coming from space. These are the echoes of DL9MS that departed from northern Germany, on the Baltic Sea, after hitting the Moon, come back and after having traveled almost 720,000 kilometers, they are captured by my antenna. His call sign comes clear: “CQ DL9MS JO54”, with a DT of 2.5

seconds. Those 2.5 seconds undoubtedly mean that this signal coming from the Moon. I cannot believe it. My emotion is huge. But I do not have much time, because the Moon is rising inexorably and is already 8 degrees above the horizon. I am excited but I concentrate because I must follow the correct procedure. I have never made an EME QSO before. I cannot afford mistakes; I would risk compromising everything*. "Pick the rose when it's time, you know time flies… and the same flower that blooms today will wither tomorrow"* because I know I have a simple 13 element Yagi antenna, without elevation and I can have only 100 watts. I know very well that when the Moon has risen above 15 degrees, I will have no more hope, my antenna would no longer "see" the Moon. I start calling. I feel like the heroes of the Apollo 11 mission, the space mission that brought the first humans to the moon. I feel like I am Neil Armstrong, as he is about to land. Dreaming costs nothing and if you close your eyes, you can go everywhere. William Shakespeare said that we too are made of the material of which dreams are made; and our short life is enclosed in the space and time of a dream. Someone or something, decided that was good and incredibly, DL9MS, immediately answers my call, and sends me his report. It is a fantastic -24 dB. But for me, any number would have been great. It is 17:41 UTC, when I see the two dotted lines appear on the screen identifying the RRR that Joachim is sending me. That is the confirmation that my signal has been received and the bilateral QSO has been made. It was not a mistake. I had "flown" for those fantastic 720,000 kilometers. I will never forget that day because I arrived on the moon. There is a saying in the EME community: "After your first EME QSO, nothing will be the same again." There is some truth. That night the Moon was magical, and before it escaped my antenna, I was able to do a second QSO. This time with a Russian station, RK3FG.

The moon rising on January 1st 2010



The signal received by DL9MS. These are the two dotted lines that transmit the DL9MS RRR message

The adventure with DL9MS did not end there. I have another telling story. I did some other QSOs via EME. Meanwhile, my VHF station had grown. I had added a second antenna, but for reasons of space, I had to make the first one smaller. The result was an array of 2 8-element Yagi antennas, 2 lambdas in length and coupled horizontally. I also joined a new power amplifier, from which I was able to pull out at least 200/220 watts, continue. One day while listening the echoes of DL9MS via the moon, I also received an outstanding signal via Troposphere. The distance between Thiene and Northern Germany is 936 Km. DL9MS is located near Rostock on the Baltic Sea. This is a typical distance for HF communications, also considering my position at the foot of the mountains, with the Alps acting as an impassable bulwark. A sort of mission impossible. But not completely impossible because one day I was also able to receive the DL9MS tropospheric signal. An imperceptible signal at -29 dB, but still a signal. It was a big surprise. I have always been inspired much more from weak signals than strong ones. The lesson I learned from this experience is: do not take anything for granted. I had the antennas directed towards the moon in a westerly direction, at 270 degrees azimuth and elevated 24 degrees above the horizon. I did not even have the antennas pointed directly at DL9MS. But despite this, a signal phantom has arrived, 5 dB lower than his same signal reflected from the Moon (via EME was -24 dB). I suspect some reflection somewhere, but difficult to say where. An electromagnetic wave that starts in Northern Germany and goes towards the Moon could go anywhere. The reflection took place on the nearby mountains of the “small Dolomites,” which I have just to the west. The peaks of the Small Dolomites (The Carega height is 2259 m.a.s.l.). But who can say for sure? This remains a mystery to be solved.

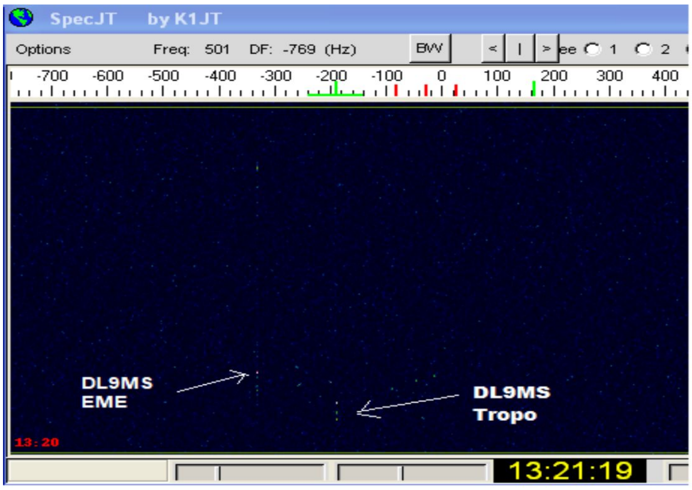


Fig. EME signal and DL9MS trope signal of 5 September 2010. 13:21 UTC. In the 144 MHz band. The QRB is 936 kilometers.

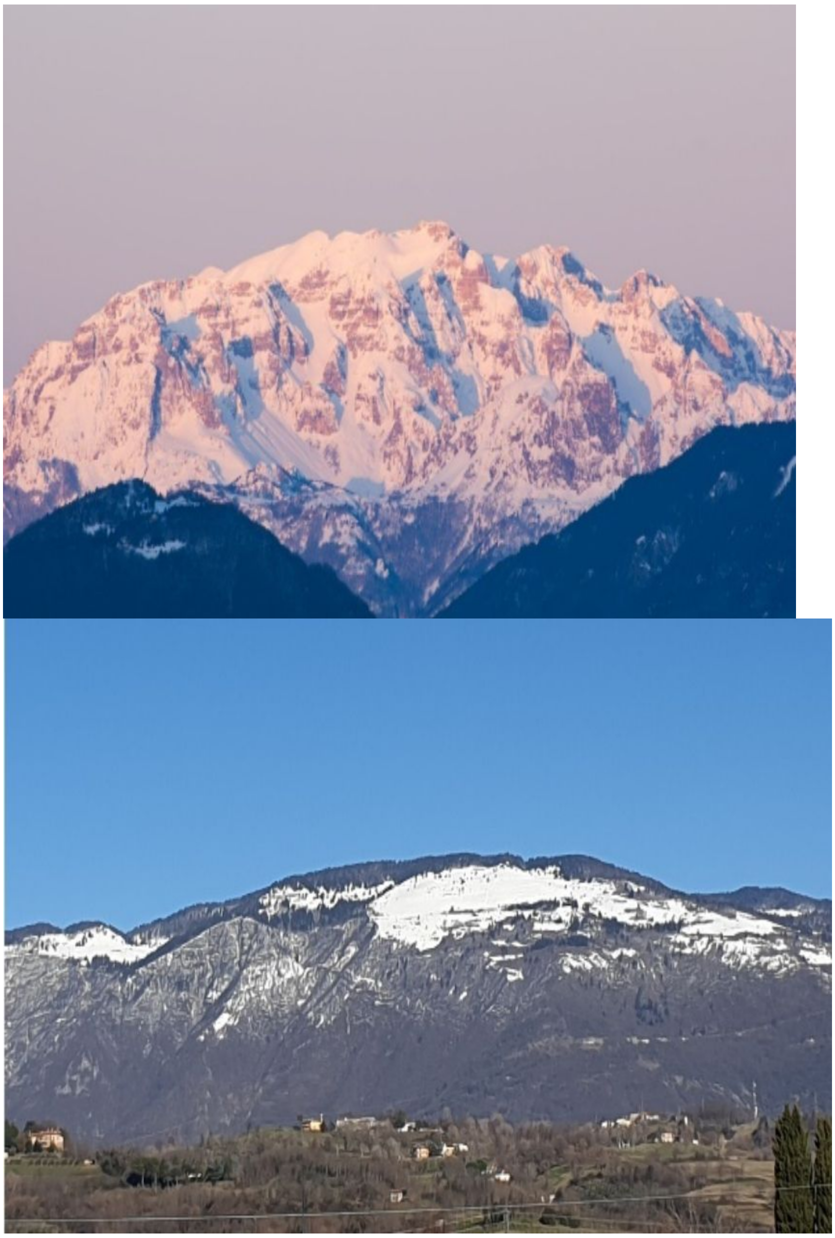


Fig. My take off towards the North. On the left side, you can see the Vicentine Prealps, which have an average height of 1500 meters above sea level (m.a.s.l.). On the western side, the Carega peaks rise to 2256 m.a.s.l. (photo above, right side).

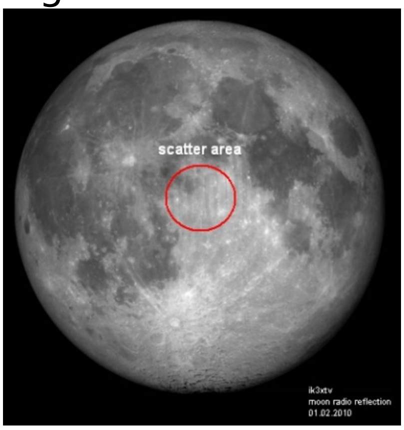
The reflection of radio waves on the lunar surface

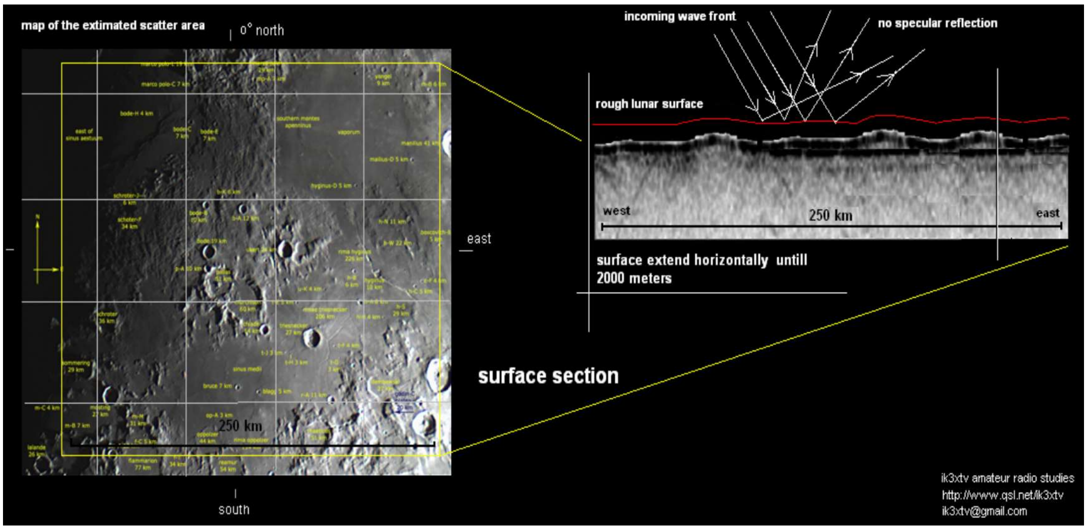
In these next chapters you will find specific studies on some aspects of moon bounce propagation. You will find some subjects that have already been dealt with in part, others dealt with in a different and more detailed way.

There are many factors that complicate radio contacts by reflection on the moon (moon bounce propagation). In addition to the great path attenuation, the EME signal must cross the Earth's ionosphere twice, with quite different portions of ionosphere. Due to this transit, it undergoes the rotation of Faraday, which introduces a phase shift that often does not allow any reception. But we do not know whether, for example, this ionospheric step can at certain times introduce favorable action. On the "Moon side" we know that not the entire surface of the satellite has the same characteristics of reflection indeed it seems that the areas that contribute most to the reflection are in the center of the visible disk. We do not know if there are other factors that can favor propagation. On the earth side, on the other hand, there are numerous factors that can worsen and why not at certain times increase the signals: Not only the ionosphere but the Earth's magnetic field and above all the magnetosphere that the moon crosses every month in the full moon phase. The aim of this research is to analyze in more detail the various elements that contribute to EME propagation.

Angle of incidence

I believe the Earth's magnetosphere can play a non-secondary role in the dynamics of earth-moon-earth propagation. In addition to this hypothesis, I have observed that even via the Moon, as is the case with HF propagation, there may be favorable angles, in my case they are simpler Europe-Europe connections/listens, especially EU-EU eastwards. Think of the earth-moon-earth angle that connects, for example, two stations on different continents, the radius of reflection incidence on the moon can differ by up to two degrees. This has an impact on both the earth side (ionosphere) and the moon side as it can change the angle of incidence on the lunar surface and thus affect the quality of the reflected signal. Something similar also happens with libration (see notes). Some research confirms that the area of greatest lunar reflection is in a limited area and indicatively in the center of the visible disk, even small movements of this area due to libration and to a different angle of incidence of the wave beam, can have a significant impact on the intensity of the return echo. The best hours to operate are at night, as the noise is lower and the ionospheric attenuation is lower, in 144 MHz it is worth about 0.5 dB, this value at night is about 10 times lower.





map of the extimated scatter area
0° north
east
south
250 km
surface section
incoming wave front
no specular reflection
rough lunar surface
west
250 km
east
surface extend horizontally untill
2000 meters
ik3xtv amateur radio studies
http://www.qsl.net/ik3xtv
ik3xtv@gmail.com

In the figure above it can be seen that the lunar surface is not flat but full of craters and depressions of km deep with mountain ranges. With the libration of the moon the effect on radio signals reflected from this area can be dramatic. The image represents the area delimited by the red circle and should contribute to the greater reflection of the EME signals.

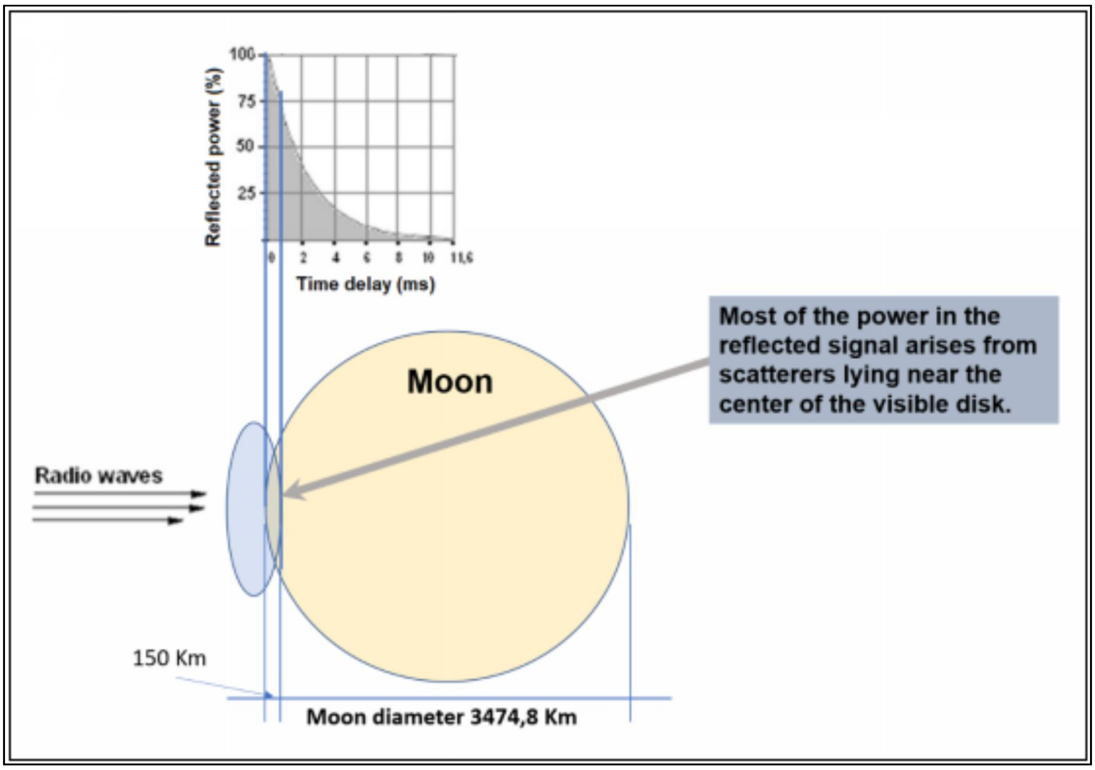


Fig. In the previous page: radio property of lunar surface. Most of the power in the reflected signal arises from scatterers lying near the center of the visible disk.

Libration

In astronomy, the term libration (derived from the Latin libra that mean balance) describes an apparent movement of the Moon relative to the Earth, which can be compared with the movement of two plates of a scale with respect to the equilibrium point. Although the rotation period of the Moon around its axis is equal to that of revolution around the Earth, libration allow an Earth observer to see slightly different portions of the lunar surface each time. These variations are caused by the Moon rotating around its axis at a constant pace, but it spins around the Earth at a variable rate, being in an elliptical orbit and moving faster when it is closer to Earth and slower when it is furthest away. The final effect is that, instead of half, only 42% of the lunar surface is always visible, another 42% is always hidden, and another 18% oscillates between the visible and hidden portion of the surface. There are three types of liberation: Libration in latitude is a consequence of the fact that the axis of rotation of the Moon is slightly inclined with respect to the perpendicular to the plane of its orbit. This generates libration in a comparable way to how the inclination of the Earth's axis generates the seasons. Longitude libration comes from the slight eccentricity of the Moon's orbit around the Earth, so that eventually the Moon's rotation is slightly further or further back than it should be relative to its position in its orbit. Finally, there is a small effect called parallactic or diurnal libration, which is a movement of the observer and not of the Moon. As the Earth rotates, an observer will look at the Moon from slightly different angles throughout the day. The relative movement affects the EME between two stations because both stations are affected by this movement as they see the moon from a different angle from each other due to their different geographical position. The reflection on the lunar surface introduces some changes to the signal:

1 – Due to the speed of the earth relative to the moon, the signal undergoes a displacement of the average frequency (Doppler effect).

2 – the reflection surface on the moon has an oscillation motion (libration) that causes doppler effect on the signal, so what is reflected is the sum (algebraic, i.e., sum or subtraction depending on the relative phase) of these reflections, each of which has a slightly different frequency. The receiving station, also with some relative movement, adds its effects, so the received signal has been modified twice. This widening, from a single frequency to a narrow spectrum (Doppler Spread), varies over time and varies depending on the location of the stations concerned. Enlargement can have a minimum, and it can also be null at certain times. Its maximum is also a function of the band used and increases linearly with frequency; in 144 MHz it is a few hertz, to reach almost 300 Hz at 10 GHz.

Let us look at the effects:

Receiving in CW

It is known that the frequency at which the receiver will have to be tuned will have to be changed by the doppler, intended only as a displacement, not as an enlargement.
It is known that the signal has a periodic change in intensity (QSB), fast or slow.
What QSB are we going to find? Its period, in seconds, is the inverse of enlargement in Hz.
If we have a strong enlargement, we will have a rapid QSB; if the enlargement is small, fraction of Hz, we will have a QSB with a period of a few seconds.
If quick it can alter the CW signal, which is an on/off, inserting "off" that can make a point disappear or split a line in two places. If slow it can erase some characters.
The classic defense is to slowly convey and repeat the message so many times.

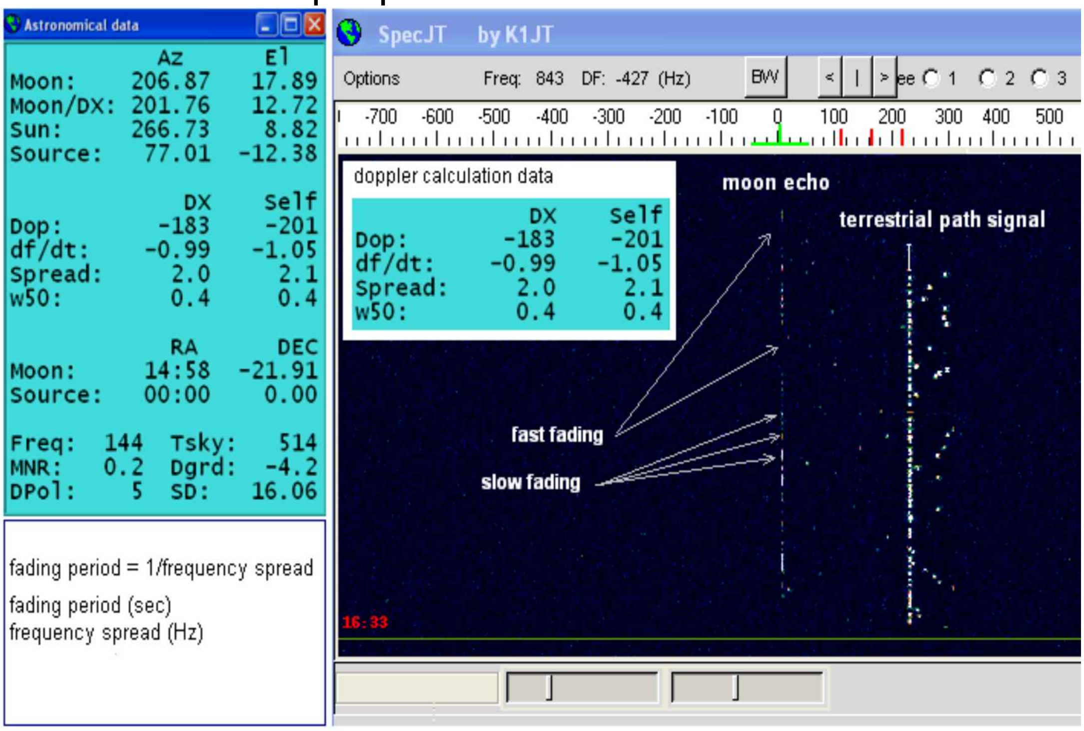
Digital reception

The modulation of the WSJT is FSK, that is, it transmits many tones, continuously.

When receiving, the tones must be identified by the decoding algorithm.

If during the minute, because of enlargement, a tone moves until it eventually has the initial frequency of another tone, decoding fails. That is why there are the three A, B, C modes of JT65, with 2.7 Hz spacing for HF and 50 MHz; 5.4 Hz for 144 and 432; 10.8 Hz for 1296; and the JT4 mode has 7 different spacings, the highest that reaches 315 Hz, suitable for 10 GHz.

You will no doubt have noticed the slow QSB by observing the variation in brightness of the trace on the JT65 waterfall; the numerous repetitions of the message also have the same purpose here as the CW.

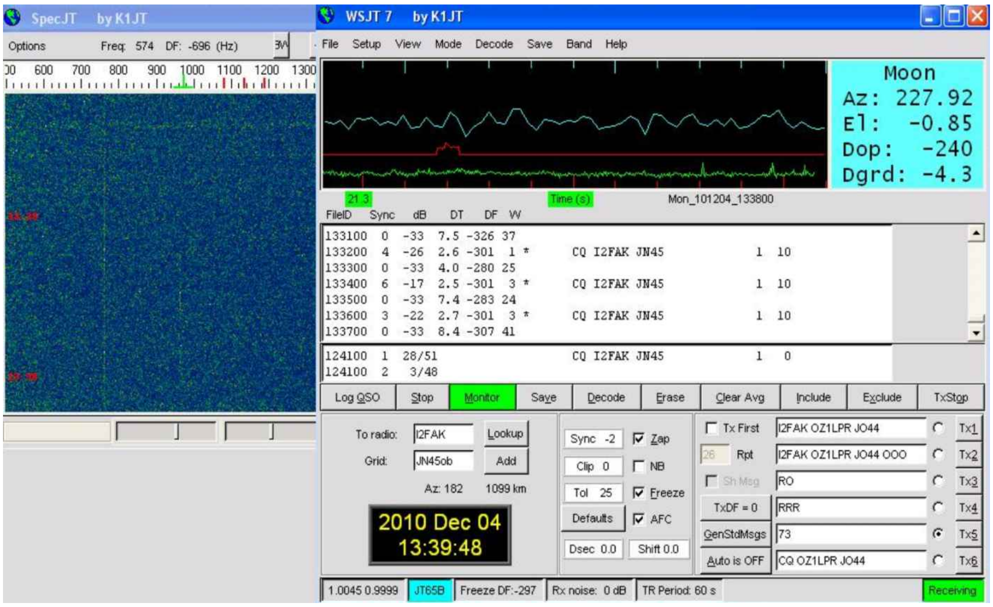


Ionospheric variability
The heme signal must pass through the Earth's ionosphere twice. For frequencies of 144 MHz the ionosphere is not completely opaque and therefore the influence of it on the signal in transit is by no mean negligible. The EME signal can pass through areas with hugely different electronic content, e.g., difference between day and night, presence of D layer, etc.
Below are some ionospheric complications that can impact EME propagation:
-Terminator
-TID mobile ionospheric disorders
-Equatorial anomaly
-South Atlantic anomaly
-Aurora
While the effects that the ionosphere produces on the signal are:
-Faraday rotation
-Dispersion of the radio wave
-Attenuation of the radio wave

A little practical experience also leads me to reflect on the importance of ionosphere conditions on EME propagation. Infect, I had the opportunity to operate in the summer afternoons within theoretical way, good conditions (low degradation, low level of cosmic noise, moon at the perigee, etc.) the signals were blocked or strongly attenuated for a strong ionospheric absorption induced by intense solar radiation, even with problems related to the low atmosphere (troposphere).
In this case it is highlighted accentuated and rapid rotation of faraday. These phenomena affect smaller EME stations, more than big stations.

Influence of the Earth's atmosphere

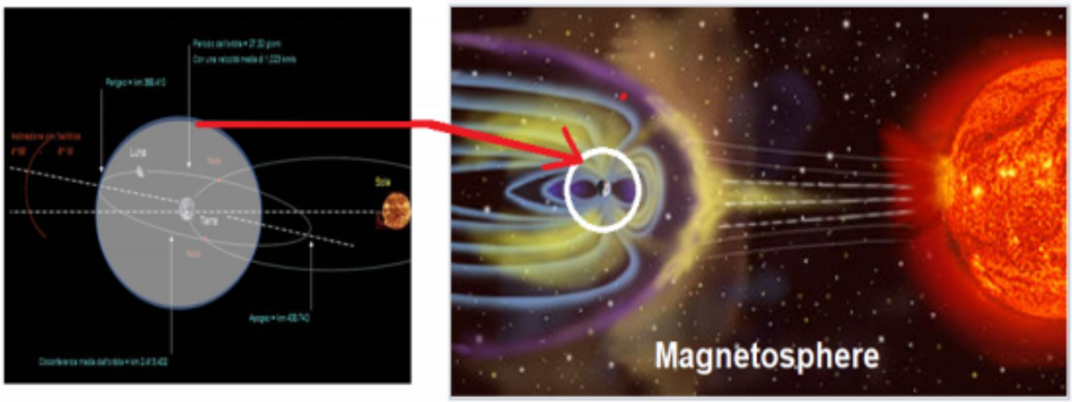
The Earth's atmosphere plays a key role in EME propagation. Especially with low elevations, it does not seem to be completely transparent at least at the frequency of 144MHz. OZ1LPR Peter told me that he had also received the echo of I2FAK with the moon already hidden from the optical horizon (as shown in the figure below). I also received the echo of I2FAK with moon already set behind the mountains.
In the first case the echo reflected by the moon was diverted from the troposphere beyond the visible horizon, in my case, it is most likely an "Edge knife" diffraction introduced by the mountains.



SpecJT by K1JT
Options Freq: 574 DF: -696 (Hz)
WSJT 7 by K1JT
File Setup View Mode Decode Save Band Help
Moon
Az: 227.92
El: -0.85
Dop: -240
Dgrd: -4.3
Time (s)
Mon_101204_133800
FileID Sync dB DT DF W
133100 0 -33 7.5 -326 37
133200 4 -26 2.6 -301 1 * CQ I2FAK JN45 1 10
133300 0 -33 4.0 -280 25
133400 6 -17 2.5 -301 3 * CQ I2FAK JN45 1 10
133500 0 -33 7.4 -283 24
133600 3 -22 2.7 -301 3 * CQ I2FAK JN45 1 10
133700 0 -33 8.4 -307 41
124100 1 28/51 CQ I2FAK JN45 1 0
124100 2 3/48
Log QSO Stop Monitor Save Decode Erase Clear Avg Include Exclude TxStop
To radio: I2FAK Lookup
Grid: JN45ob Add
Az: 182 1099 km
2010 Dec 04
13:39:48
Sync -2 Zap
Clip 0 NB
Tol 25 Freeze
Defaults AFC
Dsec 0.0 Shift 0.0
Tx First I2FAK OZ1LPR JO44 Tx1
Rpt I2FAK OZ1LPR JO44 OOO Tx2
Sh Msg RO Tx3
TxDF = 0 RRR Tx4
GenStdMsgs 73 Tx5
Auto is OFF CQ OZ1LPR JO44 Tx6
1.0045 0.9999 JT65B Freeze DF:-297 Rx noise: 0 dB TR Period: 60 s Receiving

The Moon and the Magnetosphere

In the motion of revolution around the earth, the moon enters the tail of the earth's magnetosphere once a month. This happens in the full moon phase. The moon receives a significant dose of particles from the tail of the earth's magnetosphere that extends far beyond the moon's orbit. According to Tim Stubbs of the University of Maryland and the Goddard space and flight center, this can have consequences ranging from lunar storms to electrostatic "dust" or discharges. When the moon is full it is inside the magnetic tail, it enters it three days earlier and the crossing of the magnetic tail takes about six days. During this phase, the Moon encounters a gigantic plasma made up of charged particles trapped in the tail that electrostatically charge the moon. Could this situation also impact the quality of radio reflection on the lunar surface? It is a puzzling question to answer, but this could be one of the additional factors that contribute to improving the conditions of the radio wave scatter on the moon surface.



The Earth-Moon-Sun orbital system

Image: set of two images elaborated by the author. (Images Wikipedia - NASA - Public domain).

Ionospheric attenuation

Ionospheric absorption at 144 MHz at night can vary from 0,05 dB, while daytime absorption is about ten times greater. In extreme conditions you can have up to 10 dB of absorption. Absorption decreases with the square of the frequency. For an elevation of 90°, in 144 Mhz we can have an attenuation of about 0.1 dB. This is for a single passage in the ionosphere. However, this is still a negligible value. For example, at 15 degrees elevation this value becomes about 4 times larger so considering 2 ionospheric passages we will then have Attenuation (144 mhz) = 2*4*0.1 = 0.8 dB. Due to variations in the ionosphere (time of day, solar activity, latitude, turbulence) in the worst case this factor can increase up to 10 times. We can then have absorption levels up to 8 dB/10 dB.

Ionospheric attenuation

Ionospheric attenuation is proportional to the lenght of the route through the electron plasma, to the density it encounters, and to the angle of incidence. It is proportional to the inverse of the square of the frequency. Attenuation is additive, greater the route through the plasma, greater the attenuation. The graph here under refers to 100 km of depth. The table covers typical values of total attenuation for a single passage through. Variations in the ionosphere (time of day, solar activity, latitude, turbulences) can increase these values.

Typical daytime conditions
(single passage through the ionosphere)

Elevation Angle	Attenuation in dB for Height in Km		
	100 Km	300 Km	500 Km
0°	0,6	1,8	3,0
30°	0,2	0,6	1,0
60°	0,12	0,36	0,6

Ionospheric scintillation

Rapid fluctuations in the ionospheric refractive index cause scintillation on signals passing through the ionosphere. These are rapid variations in amplitude and/or phase. This phenomenon is known and studied by those who deal with GPS positioning systems as these rapid signal fluctuations can cause significant ground positioning errors (in the most extreme cases even in the order of tens of meters). These effects decrease as the frequency increases. Scintillations are most marked at high latitudes, in the equatorial belt and during geomagnetic storms.

In summary, therefore, we have:

- "Almost periodic" variations with a period of min/tens of minutes that should be due to turbulence of the Ionosphere.
- Very rapid variations (rapid QSB) with a period of sec/tens of sec. due to ionospheric scintillation (e.g., the rapid QSB that is often observed during a JT65 transmission sequence).

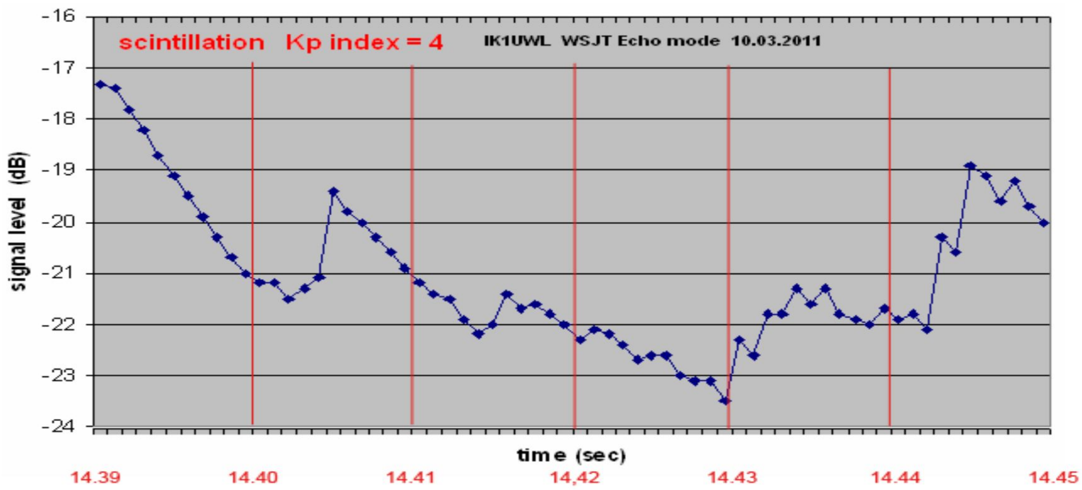


Fig. The graph shows a self-listening test of his own echoes made by Giorgio, IK1UWL with his 4 Yagi EME antennas where a scintillation effect is highlighted. The interval covers 6 minutes of continuous echoes emitted at short interval. About one echo every 5 seconds. Note the significant variations in dB of the signal.

There are indices that allow you to observe the behavior of the ionosphere with good approximation. Let us see them:

TEC Total electron content The Total Electron Content (TEC) is the descriptive key parameter of the Earth's ionosphere. Represents the total number of electrons along a path between two points, measured in units of electrons per square meter, with 1 TEC unit (TECU) = 10^{16} electrons/m^2. TEC is critical to determining the scintillation and group delay of an electromagnetic wave through a medium. GPS satellites are used to measure TEC using the radio occultation technique. It has a progressive pattern throughout the day that follows the zenith movement of the sun, but there may be significant temporal/local variations related to smooth movements in the ionosphere, turbulence, and local variations of the magnetic field.

Daily pulse of TEC

At night, the recombination of ions and electrons takes place, with a decrease in TEC. By day, the split predominates, with an increase in the TEC. Lows and highs, however, are

staggered. The TEC goes up before sunrise and descends before sunset. The cause? The ionosphere is home to strong east-to-west winds.

Planetary index Kp

An indication of the level of geomagnetic disturbance on a planetary scale is provided by the Kp index which is the average of the K index values recorded at 13 reference observatories. This index is used for prior discrimination of quiet days from disturbance days.

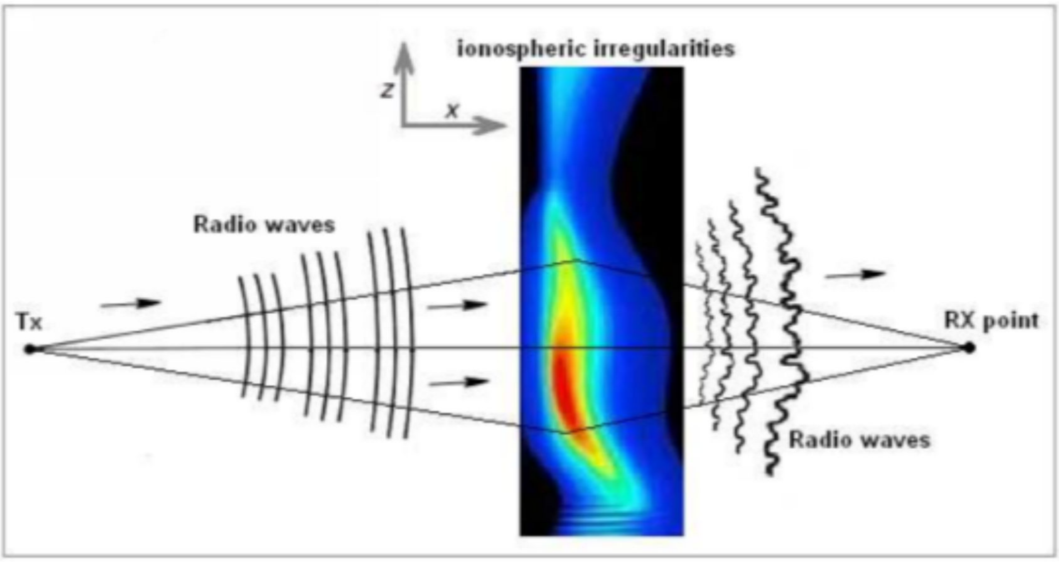
Index

It provides a measure of geomagnetic activity originating from corpuscular radiation from the Sun after eliminating the regular daytime variation produced by electromagnetic solar radiation.

The role of the Ionosphere in EME communications

Earth's ionosphere

The ionosphere is a non-homogeneous medium, where the electron density varies with altitude, but there are also horizontal gradients. It is a non-isotropic system because the ionized component is immersed in the Earth's magnetic field. In fact, we can talk about a plasma magneto. In addition, the ionosphere has significant daytime and seasonal variations, due to variations in solar radiation. The ionosphere is turbulent and subject to continuous wavy movements.



The mechanism of Ionospheric scintillation.

The analogy between electromagnetic waves and optical waves

The radio wave does not differ in any way from the optical wave except for the wavelength and therefore the frequency. Both units are in fact bound to the constant C (speed of light) if wavelength lambda increases, the frequency F, must decrease.

$c = \lambda * F$

The ionosphere, in general, acts as a refractor for radio waves because it behaves like a dielectric with the constant that is <1 i.e., lower than the dielectric vacuum constant.
If-the signal arriving through a path in the ionosphere, it is affected by scintillation (Fast Fading) there are no other alternatives or passed through a turbulent refractor or through a refractor, which contained many irregularities.

Location of ionospheric irregularities
Ionospheric scintillations are related to electron density. The increase in electronic density occurs at a height between 200 and 300 km (F layer), so it is extremely likely that most disturbances originate in this area.

Total electron content (TEC) daytime variations
During the night, the recombination of ions and electrons takes place, with a decrease in TEC. During the day, the ionization process predominates, with the production of free electrons, with an increase in TEC. However, the minimum and maximum values are compensated. The TEC begins to rise before sunrise and begins to decrease before sunset. What is the cause? The ionosphere is home to strong east-west winds.

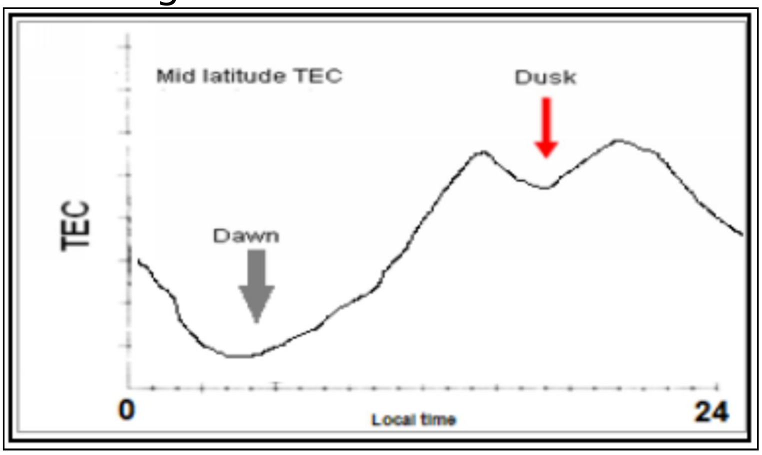


Fig. In this graph we can see a minimum TEC level before sunrise (minimum before sunrise) and a marked TEC depression before sunset.

Seasonal variations of TEC

We have seasonal variations in the total electron content and variations related to the eleven-year cycle of the sun. In addition, there may be significant daily variations.

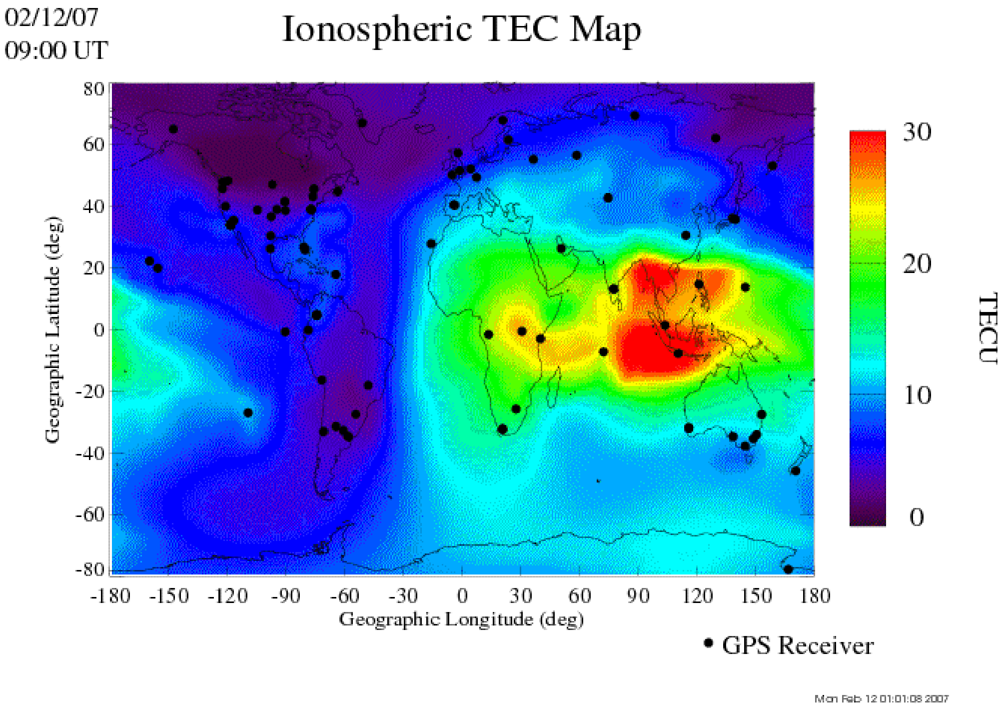


Fig. Snapshot of the electron density in the ionosphere, measured by GPS ground stations.
(Image Author: NASA, Jet Propulsion Laboratory- public domain from Wikipedia)

Ionospheric scintillation
Ionospheric scintillation is a rapid fluctuation in the amplitude and phase of radio signals passing through the ionosphere due to turbulence caused by ionospheric irregularities. Irregularities in the ionosphere cause variations in the refractive index and thus produce scintillations on the intensity of the signals. The Earth's ionosphere is a plasma with its irregular structure that forms a random diffraction screen. Irregularities are always present. Scintillations are caused by plasma agglomerations/bubbles located between E and F region of the constantly moving ionosphere due to the turbulent nature of the ionosphere. These agglomerations/ionization bubbles function as concave/convex radio lenses. In EME communication we have a double transit through the ionosphere (ionospheric effects are additives). The amplitude of the scintillation is inversely proportional to the square of the frequency. In VHF the ionospheric component prevails while at the highest frequencies the component due to tropospheric scintillation prevails.

Properties of the lunar surface
A brief note on the reflective properties of the lunar surface: as evidenced in the diagram below, the reflection coefficient of the lunar surface decreases as the frequency increases. (The echo of the moon is almost mirrored in VHF; the diffusion increases at the highest frequencies). For a variation from 0.05 to 0.1 of the reflection coefficients, the change in path loss does not exceed 3 dB (at 144 MHZ).

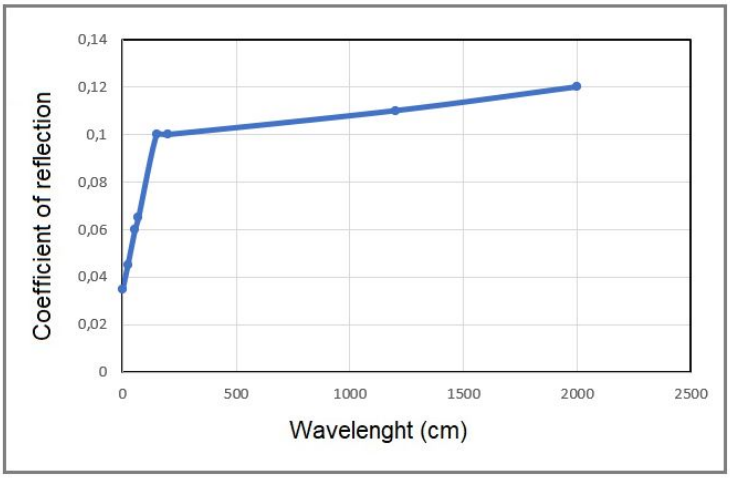


Fig. Trend of the reflection coefficient (average) as a function of frequency. Source: IK3XTV-IK1UWL.

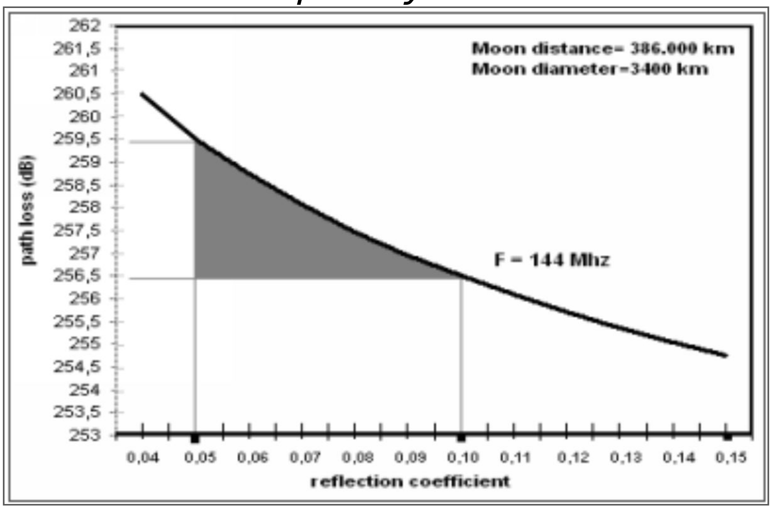


Fig. For a variation from 0.05 to 0.1 of the reflection coefficients, the change in path loss does not exceed 3 dB (at 144 MHZ)

Libration Fading

Signals reflected from the lunar surface tend to have a rapid faded fluctuation known as Libration Fading. It is caused by the moon's irregular surface, which "oscillates back and forth" from an observation from the Earth, and there is also the earth's rotational and revolution movement. Libration fade can cause signal fluctuations above and below the average level. Libration Fading fluctuation is directly proportional to frequency (fading is faster as frequency increases). So, a peak of libration that lasts 3 seconds on 144 MHz, will be only 1 second on 432 and 1/3 of a second on 1296.

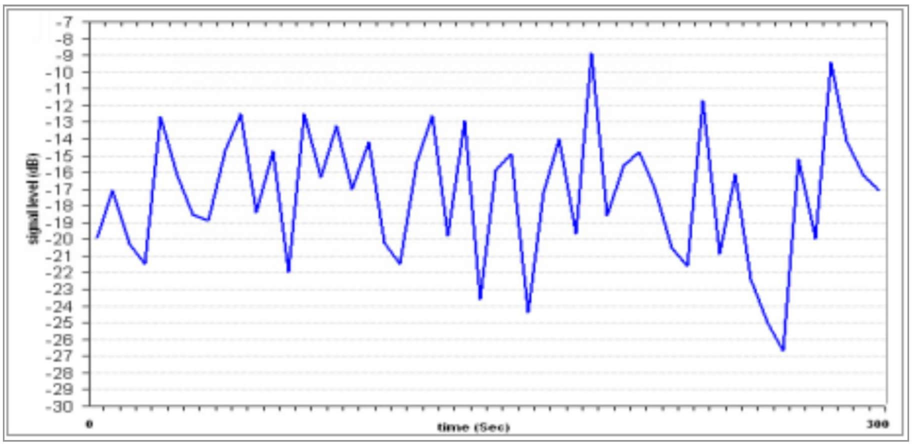


Fig. Comparison with WSJT at 144 MHZ. We found an average variation in the order of 12-13 dB due to ionospheric scintillation (at 144 MHz the libration fade is about 3dB) Tests conducted by IK1UWL with Yagi 4x16 elements with circular polarization (during quiet ionospheric day).

Fading for ionospheric absorption

Evanescence by ionospheric absorption is characterized by a very slow period: a few minutes / tens of minutes. It is due to the turbulent and unstable nature of the Earth's ionosphere.

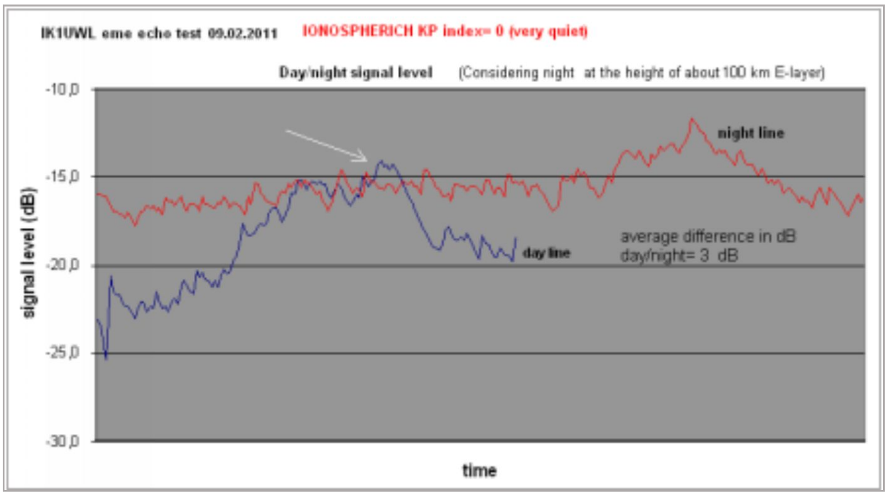


Fig. The graph shows the overlap of the day/night absorption curves. The test was conducted under stable and quiet ionospheric conditions. Under normal ionospheric conditions absorption is lower during the night hours. The white arrow indicates the peak before sunset. This is due to the action of strong ionospheric winds along the grey line, which clean the ionosphere, opening a window of lower absorption.

Faraday and f0F2 rotation

Faraday's rotation depends on the TEC and in good approximation from f0F2. Therefore, a daily monitoring of f0F2 can provide essential information on the intensity of rotations.

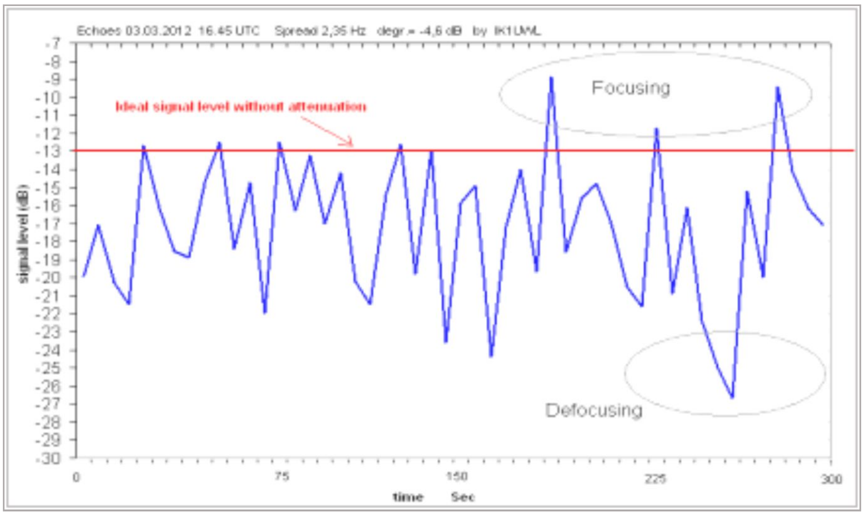


Fig. The measurements shown in this chart are made with WSJT. In addition to the strong ionospheric scintillation there are some peaks of 4 dB above the ideal line, and some negative deep peaks due to focusing or defocusing effects.

Undulations in the ionosphere
wave model: the ionospheric layers are not homogeneous, they are continuously shaped by intense winds that can have neutral ionospheric movements, zonal movements (east-west) along the parallels and meridian movements (north-south) along the meridians. In addition, there are vertical convective turbulence and AGW (atmospheric gravitational waves) that constantly shape the layers.
We can have: Small-scale irregularities (size of a few wavelengths). Large-scale irregularities (size of the order of 100 km). Irregularities tend to align along the lines of the Earth's magnetic field.

The ionospheric winds cause continuous undulations and waves (Traveling Ionospheric Disturbances, TIDs) resulting in fluctuations of electron density.

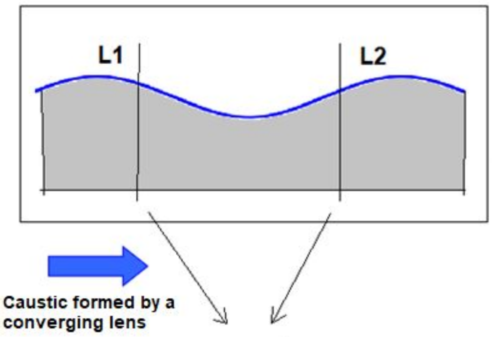
Class	Horizontal wavelenght	Periods	Horizontal phase velocities
LSTIDs Large scale	>1000 Km	0,5..3 h	300..1000 m/s
MSTIDs Medium scale	100..1000 Km	12 min...1h	100..300 m/s
SSTIDs Small Scale	<100 Km	A few minutes	<200 m/s

Ionospheric irregularities (focusing / defocusing): shape and structure

The presence of cylindrical lenticular structures in the ionosphere are the result of the vertical distribution of the electron density.

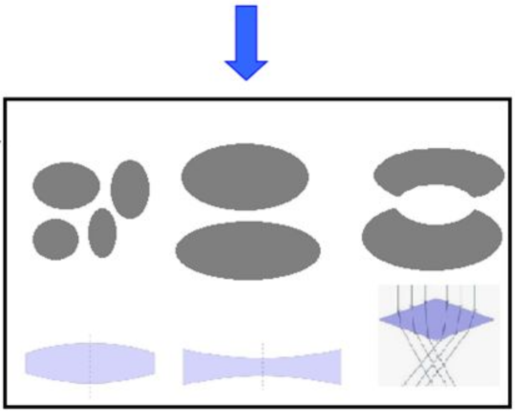
The phenomenon is due to multiple interconnected isoelectronic surfaces present within the ionosphere, mainly distributed vertically.

Electronic distribution having the correct convergent radio lens properties. Iso electronic surfaces in the ionosphere are modeled sinusoidally by the internal movements of the ionosphere.



Caustic formed by a converging lens

Various forms of lenses due to multiple distributions of electronic density with multiplicative effect. Regions of higher electron density with cylindrical (vertical) symmetry can act as a converging lens.



EME logbook by IK3XTV and IK1UWL

EME (Earth-Moon-Earth)

This is the diary of the research about EME propagation, made over several years by Flavio Egano, IK3XTV and Giorgio Marchi, IK1UWL and culminated in various presentations of the results both at the Italian EME Conferences and at three World EME Conferences, in France, Italy, and the Netherlands.

Why operate in EME?

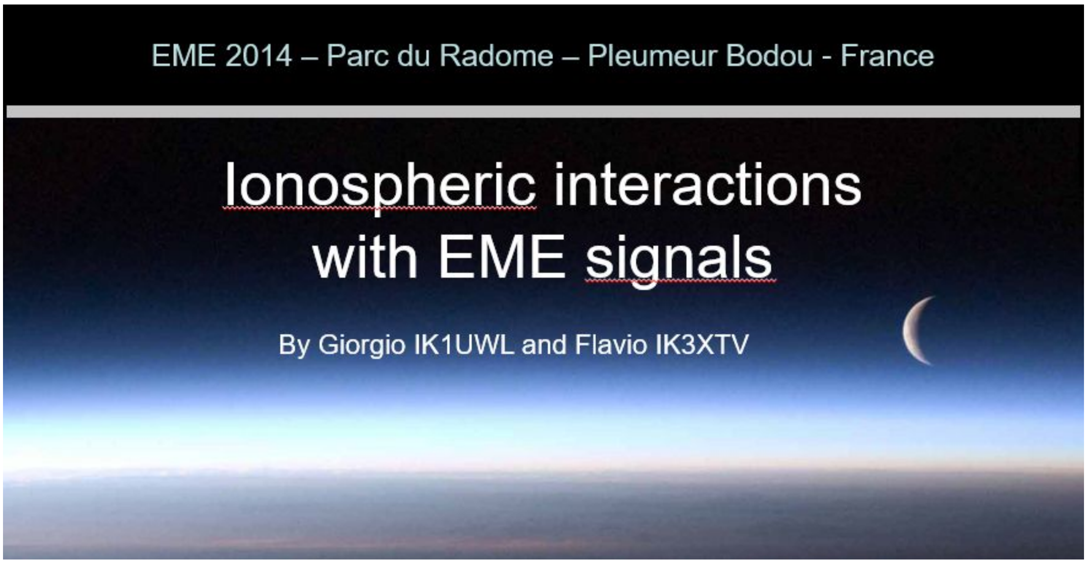
In High Frequency (HF), the ionosphere refracts signals and thus aids DX hunters in making connections across the entire world. However, from 50 MHz and above, this refraction becomes increasingly scarce. Although short or very short periods of sporadic E and Meteor Scatter can occur, they only allow for a maximum distance of a few thousand kilometers.
To establish communication worldwide, desperate measures must be taken, such as reflecting the signal off the Moon, which is at an average distance of 380,000 km. This radio communication technique encounters major obstacles:

- An incredible attenuation of your waves having to travel for 380.000 Km to meet the Moon, and only a small fraction of that waves is reflected.
- In both paths it must cross the Earth's ionosphere, which is permeable, non-transparent, to radio waves of VHF. Much of our research has been about just what happens in these crossings.

- Decoding extra weak signals. The technique has evolved. At first, telegraphy (CW) was used with very narrow band receivers and specialized filters. Then the task was passed to the computer, both for appropriate encoding of the message and for decoding with techniques derived from radio astronomy.

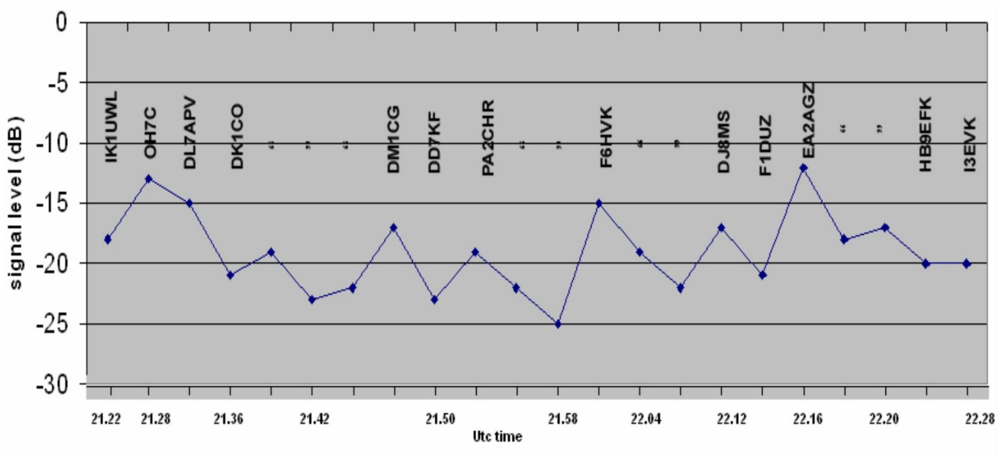
Our beginnings

We came into contact in 2011 with the intention of deepening this EME and presented our first conclusions in 2013 at the Italian EME Conference, and then at the EME World Conference in France in 2014.



The inspiration stems from an observation by Giorgio IK1UWL who during his EME activity noticed a significant QSB on the signals, not related to the phenomenon of lunar libration. When there was an active 2 meters EME DX expedition to New Caledonia, IK1UWL had a window of about an hour and had connected New Caledonia to its moonrise. FK/DL2NUD came in very strong, and after qso, IK1UWL continued to monitor the signal and intrigued by the level changes, charted the level of that DX station, which it always decoded. The QSB was 13 dB.

Note: This part of the book may be too specialized and dedicated to those who are enthusiastic about the EME world and for this I apologize.



At this point Flavio IK3XTV, a skilled internet navigator, comes into play, with whom we begin our research. New Caledonia is located near the geomagnetic equator which in that area declines very much to the south and therefore is in the tropical belt where there is greater ionospheric instability. By that time and date, New Caledonia was in full sun, with dense and turbulent ionosphere. The culprit is the ionosphere, which, even if it does not reflect on it, we must cross twice, and which interacts with our signal. Let us then look at the characteristics applicable to the EME.

Ionosphere

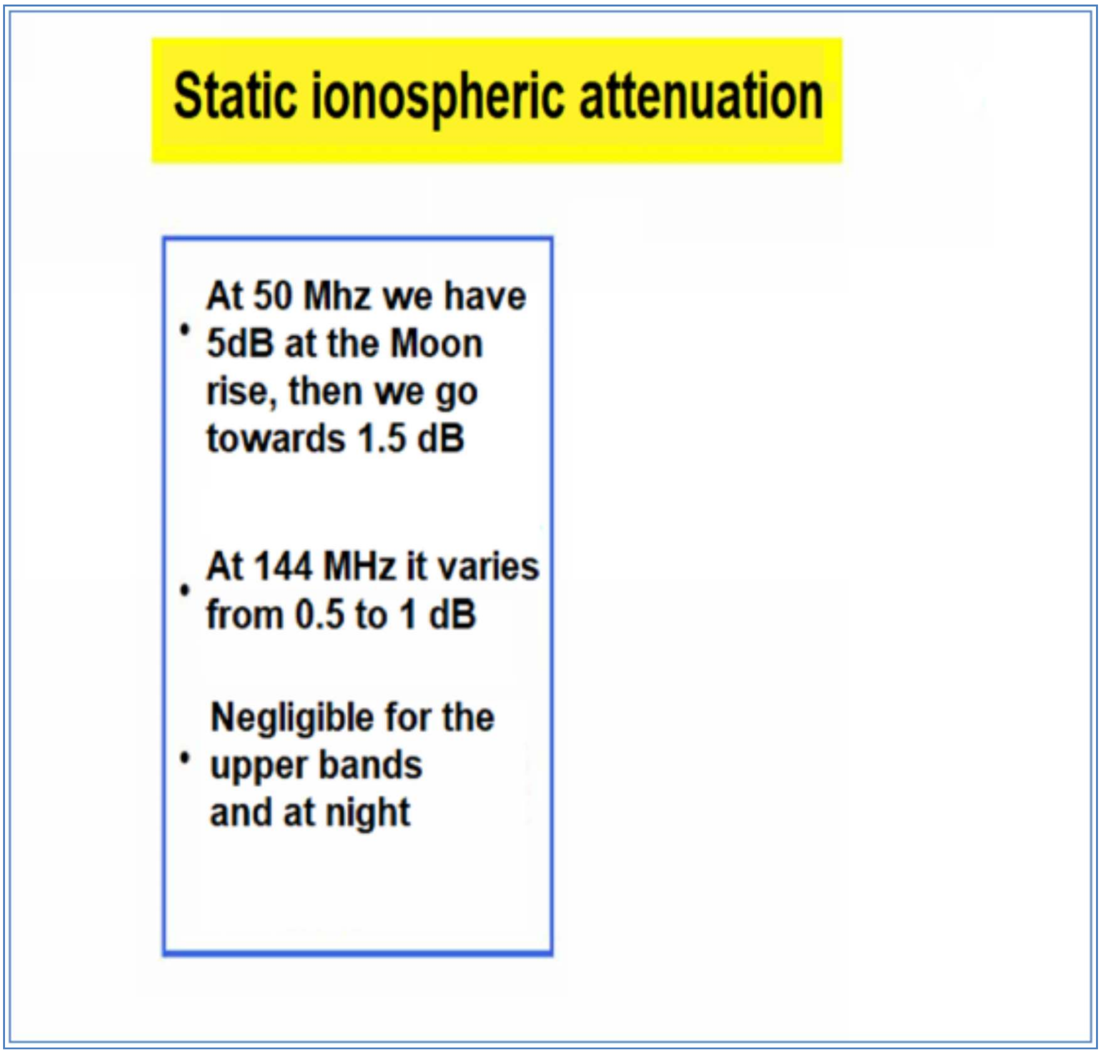
The effects of the sun:
The extreme UV and X solar radiation impacts the high atmosphere and generates a plasma of free ions and electrons

Features:
- it is a non-homogeneous medium as the electronic density varies with the altitude
- It is immersed in the Earth's magnetic field. In fact, we are talking about Magnetoplasma
- Has significant daily and seasonal variations, linked above all to variations in solar radiation
- The ionosphere is turbulent and subject to continuous wave movements

Interactions with a radio wave:
Free electrons react to the electric field of a radio wave by absorbing energy, which is returned in large part, by re-irradiation and therefore weakening it, slowing it down, deflecting it and rotating it

Free electrons interact with the radio wave, so their density determines the intensity of the effect.

The ionosphere is a seething ocean above our heads.
Flavio, IK3XTV has researched its characteristics on the Internet, trying to create an image of this world that surrounds us from above.
In particular, we wanted to ascertain the causes of QSB, which could be caused either by attenuation or diffraction.



It is evident that absorption attenuation is much smaller than observed QSB, so we can overlook it as a cause, instead deepening any diffraction effects in the ionosphere
Here are some self-explanatory slides from our presentations.

Winds and ionospheric waves

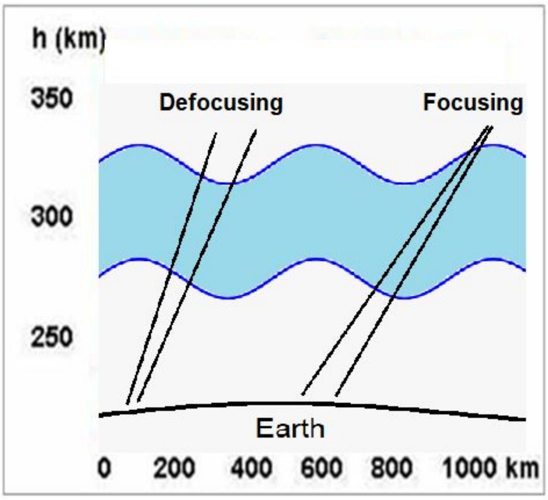
- Typically in the ionosphere there are winds of 100/500 m / s that form waves and vortices (TID)

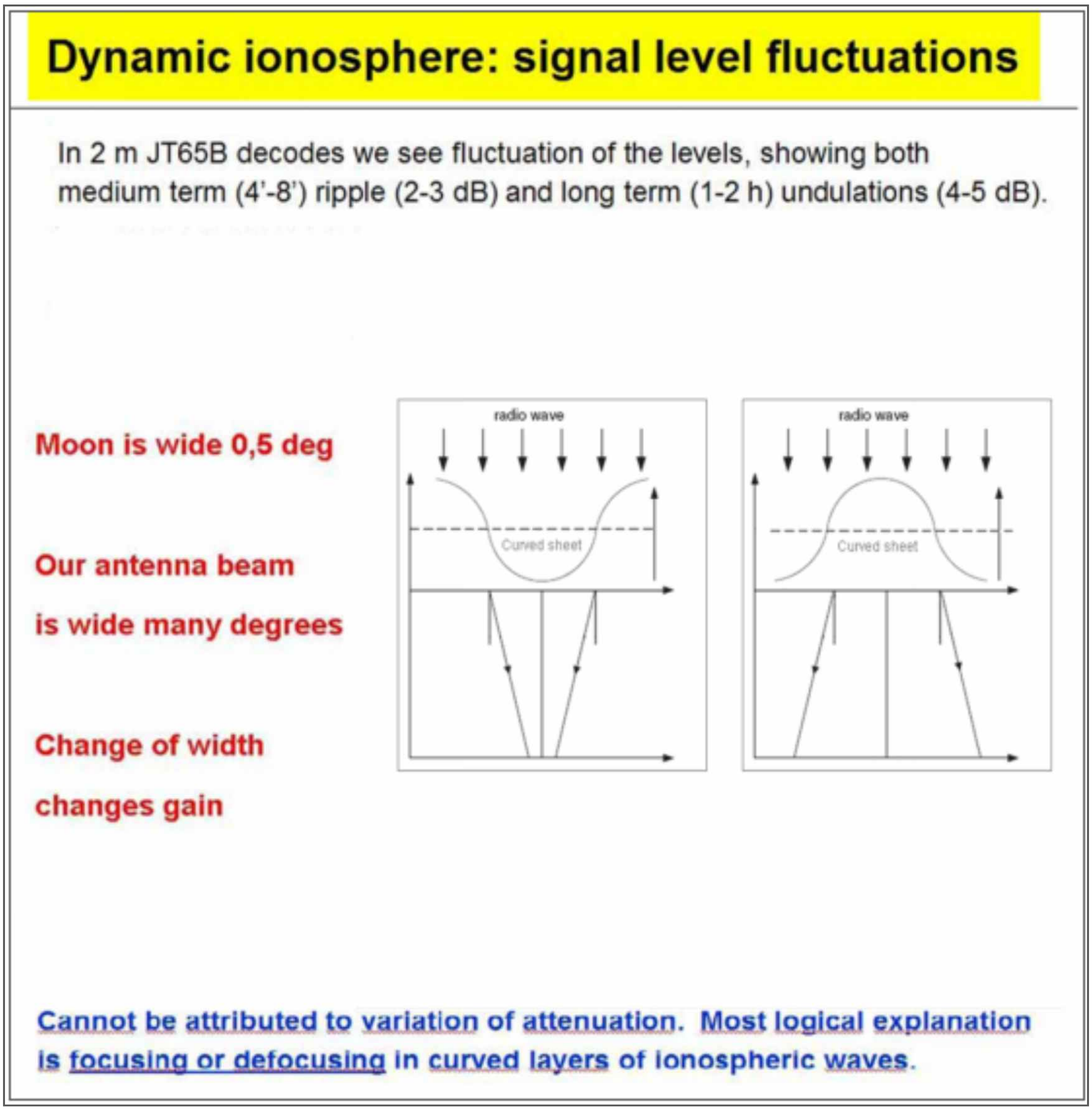
- The typical wind of 200 m / s = 12 Km / min corresponds to waves of 1000/1500 Km length on which they overlap, smaller waves about 100 km long

Focusing/Defocusing effects

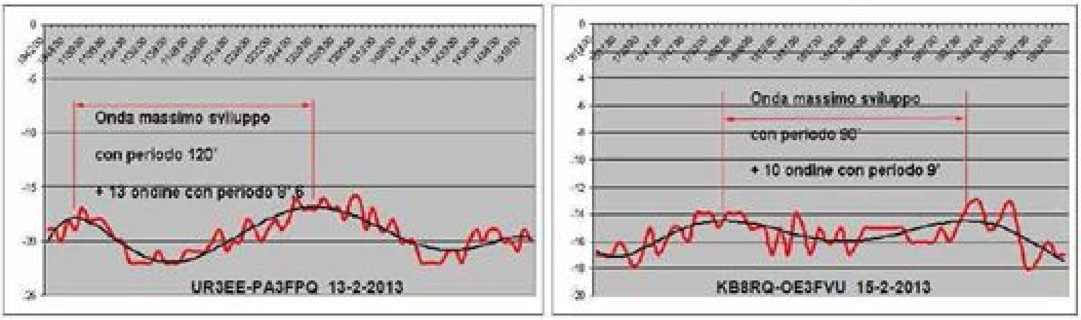
- Fast scintillations caused by lunar libration and ionospheric turbulence (**ssTIDs**, periods of minutes)

- Slower fluctuations from **msTIDs** (observed at mid latitudes every day) (300 km wavelength, wind 100 m/s = 360 km/h)





The wave beam we emitted passes through an uneven medium, which will cause refraction (concentrating the beam) or diffraction (widening the beam) in a variable way over time.
Thus, the surface density of the energy that hits the Moon and is reflected, varies over time causing the well-known QSB.



We notice a long-term fluctuation caused by large waves and shorter fluctuations caused by ripples of the waves. These two graphs come from the database we put together.
At this point we were satisfied with the explanations found for the QSB.
But we knew there was another phenomenon, related to the ionosphere: the rotation of the polarization plane.

- We need data from many stations and of many stations
- Flash of genius: take data from LIVE CQ
- We write to Renè, PE1L
- He replies:

“No need to copy and paste that way.

I will provide you an excel sheet with 'old' data and will make a page where you can get the raw data from the last month.

Rene”

LiveCQ 144 432 1296

Menu

- All spots
- Latest spots
- Who is online
- Add your CQ spot here
- User config
- Contest style
- Simple design all spots
- Mobile

Search

callsign

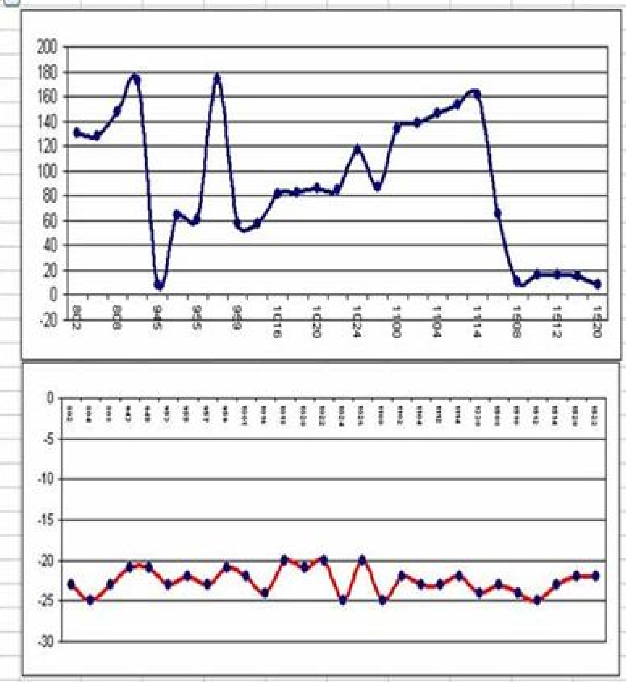
Latest 25 spots

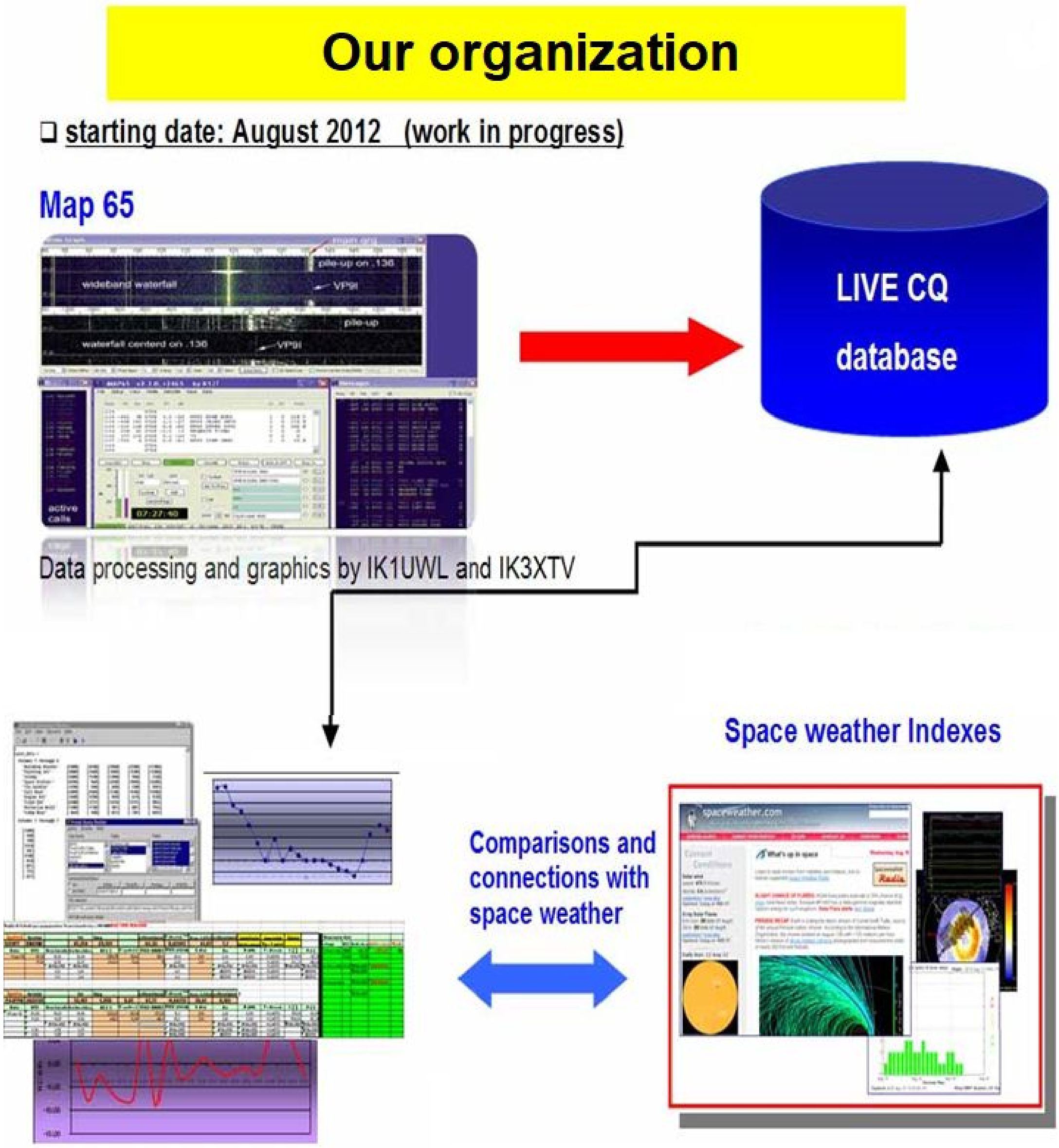
Freq	Date	Time	Signal	DF	DT		Call	Loc	Pol	M	Spotter
144.125	9-Feb	154800	-24	-158	2.2	CQ	HB9SLU	JN36	3	8	PE1L
144.126	9-Feb	153800	-24	-229	3.1	CQ	F6APE	IN97	176	8	PE1L
144.126	9-Feb	153200	-24	-379	2.3	CQ	F6APE	IN97	173	8	OZ1LPR
144.128	9-Feb	153000	-19	-123	1.6	CQ	I2FAK	JN45	10	8	OZ1LPR
144.128	9-Feb	153000	-23	-129	2.5	CQ	I2FAK	JN45	8	8	PA3FPQ
144.128	9-Feb	153000	-16	-040	2.5	CQ	I2FAK	JN45	177	8	PE1L
144.126	9-Feb	153000	-25	-385	3.2	CQ	F6APE	IN97	175	8	PA3FPQ
144.125	9-Feb	152600	-23	-214	1.3	CQ	HB9SLU	JN36	170	8	OZ1LPR
144.125	9-Feb	152400	-24	+100	1.3	CQ	HB9SLU	JN36	Y	8	W6BBS
144.132	9-Feb	151100	-20	-236	2.5	CQ	OK1DEX	JN79	90	8	OZ1LPR
144.131	9-Feb	151300	-26	-279	1.5	CQ	FM8DY	FK94	141	8	OZ1LPR

Database

- We organize the database in weekly sheets
- We can select, spotter, spotted and date

2	date	utc	sig	pol	call	spotter
1927	18082012	802	-23	130	DG0OPK	PE1L
1929	18082012	804	-25	128	DG0OPK	PE1L
1937	18082012	808	-23	148	DG0OPK	PE1L
2036	18082012	943	-21	173	DG0OPK	PE1L
2039	18082012	945	-21	8	DG0OPK	PE1L
2045	18082012	953	-23	64	DG0OPK	PE1L
2050	18082012	955	-22	61	DG0OPK	PE1L
2055	18082012	957	-23	174	DG0OPK	PE1L
2057	18082012	959	-21	58	DG0OPK	PE1L
2060	18082012	1001	-22	58	DG0OPK	PE1L
2084	18082012	1016	-24	82	DG0OPK	PE1L
2086	18082012	1018	-20	83	DG0OPK	PE1L
2090	18082012	1020	-21	86	DG0OPK	PE1L
2094	18082012	1022	-20	85	DG0OPK	PE1L
2100	18082012	1024	-25	117	DG0OPK	PE1L
2105	18082012	1026	-20	87	DG0OPK	PE1L
2135	18082012	1100	-25	134	DG0OPK	PE1L
2137	18082012	1102	-22	138	DG0OPK	PE1L
2142	18082012	1104	-23	146	DG0OPK	PE1L
2145	18082012	1112	-23	153	DG0OPK	PE1L
2148	18082012	1114	-22	161	DG0OPK	PE1L
2251	18082012	1330	-24	66	DG0OPK	PE1L
2406	18082012	1508	-23	11	DG0OPK	PE1L
2412	18082012	1510	-24	17	DG0OPK	PE1L
2415	18082012	1512	-25	17	DG0OPK	PE1L
2421	18082012	1514	-23	15	DG0OPK	PE1L
2448	18082012	1520	-22	8	DG0OPK	PE1L
2456	18082012	1522	-22	4	DG0OPK	PE1L

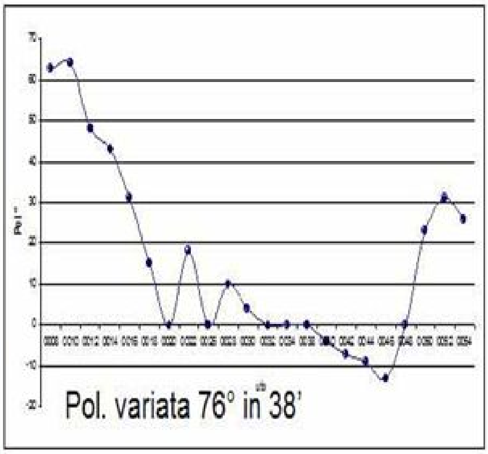


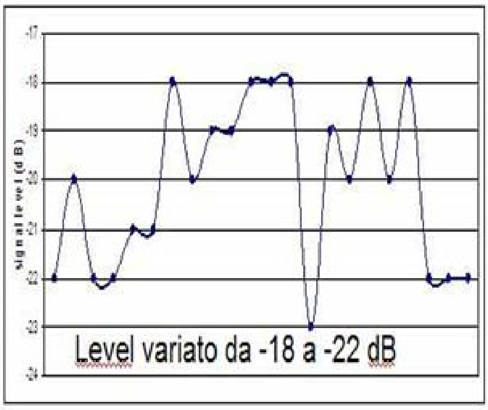


Another decoding by Giorgio IK1UWL, which uses cross-antennas with simultaneous reception of the Horizontal and Vertical components and is therefore immune from the problems related to rotation, the infamous Faraday effect.

Date: 2012-aug-03 – Station IK1UWL - Band 144 MHz

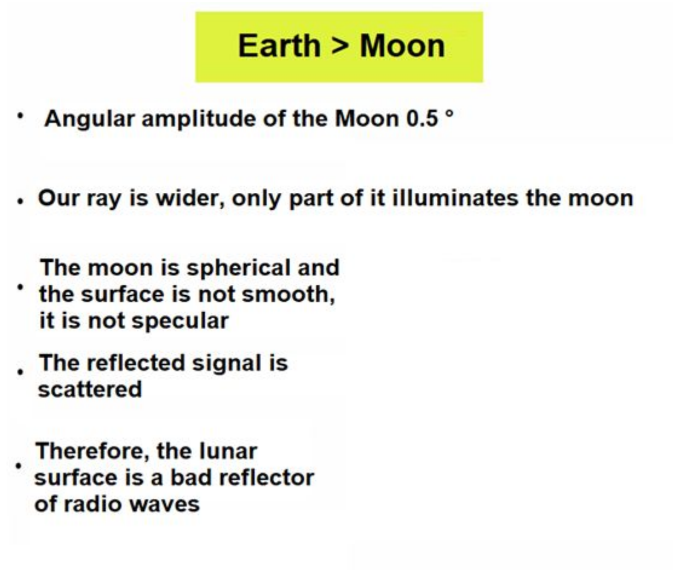
QRG	DF				DT	Pol		dB	UTC				
144.143	-129	0	-2	0	1.7	63	4	-22	0008	CQ OX3LX HP15	1	10	8
144.143	-138	3	-1	0	1.7	64	3	-20	0010	CQ OX3LX HP15	1	10	15
144.143	-144	0	-2	-1	1.7	48	3	-22	0012	CQ OX3LX HP15	1	10	5
144.143	-153	0	-2	-1	1.9	43	5	-22	0014	CQ OX3LX HP15	1	10	3
144.143	-161	1	-1	0	1.5	31	1	-21	0016	CQ OX3LX HP15	1	10	4
144.143	-170	0	-1	0	1.7	15	2	-21	0018	F6HVK OX3LX HP15 OOO	1	0	5
144.143	-176	0	0	0	3.6	0	4	-18	0020	RRR	0	0	0
144.143	-185	1	0	0	1.7	18	5	-20	0022	RK3FG OX3LX HP15 OOO	1	0	17
144.143	-191	0	0	0	1.0	0	4	-19	0026	RRR	0	0	0
144.143	-199	1	-1	0	1.7	10	4	-19	0028	CQ OX3LX HP15	1	10	3
144.143	-205	0	-2	0	1.5	4	4	-18	0030	I3MEK OX3LX HP15 OOO	1	0	16
144.143	-214	0	0	0	3.6	0	3	-18	0032	RRR	0	0	0
144.143	-217	-1	0	-1	2.1	0	4	-18	0034	IZ3KGJ OX3LX HP15 OOO	1	0	18
144.143	-226	0	0	0	1.0	0	4	-23	0038	RRR	0	0	0
144.143	-229	-1	-1	-1	1.6	-4	4	-19	0040	CQ OX3LX HP15	1	10	15
144.143	-232	-2	-1	-1	1.8	-7	5	-20	0042	CQ OX3LX HP15	1	10	12
144.143	-238	0	-1	-1	1.8	-9	4	-18	0044	CQ OX3LX HP15	1	10	10
144.143	-243	3	-1	1	1.8	-13	3	-20	0046	IK1UWL OX3LX HP15 OOO	1	0	7
144.143	-246	0	0	0	1.0	0	4	-18	0048	RRR	0	0	0





MAP65 is a research tool. In addition to decoding messages, it also measures levels in dB and polarity

Our research shifts to the ionospheric effects on the signal.



In the 1960s, the U.S. military, to try to find a method of communication with wide worldwide coverage, examined, with radar studies, the possibility of using the Moon reflector. It was the same years that amateur radio also tried this path successfully.

These radar studies have identified many factors, such as the reflection coefficient (the lunar surface is rough and wavy) and the size of the reflecting area.

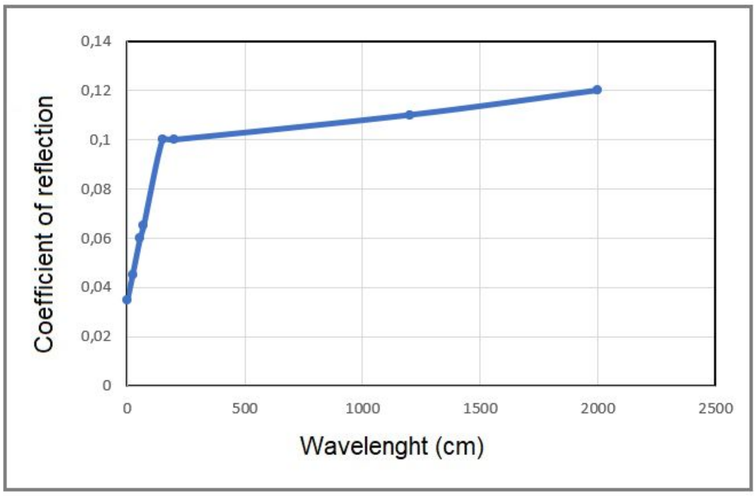
Coefficient of reflection

- It is the diffuse reflectivity, that is the ability of the surface to reflect the radio waves

- It is the ratio between reflected radiation and radiation incident on the surface

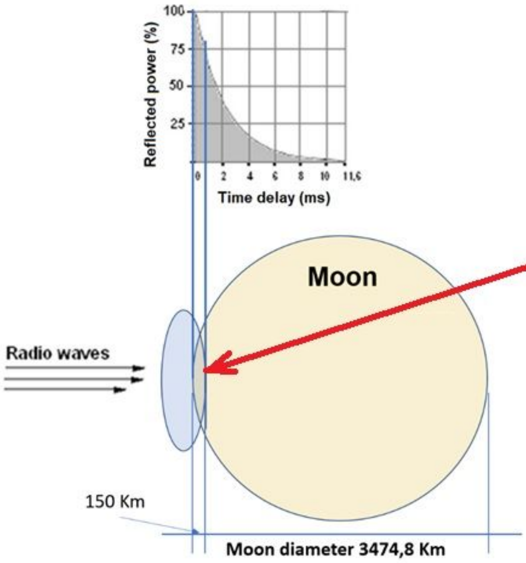
- Average values :

2 m	0,1 2
70 cm	0,065
23 cm	0,045

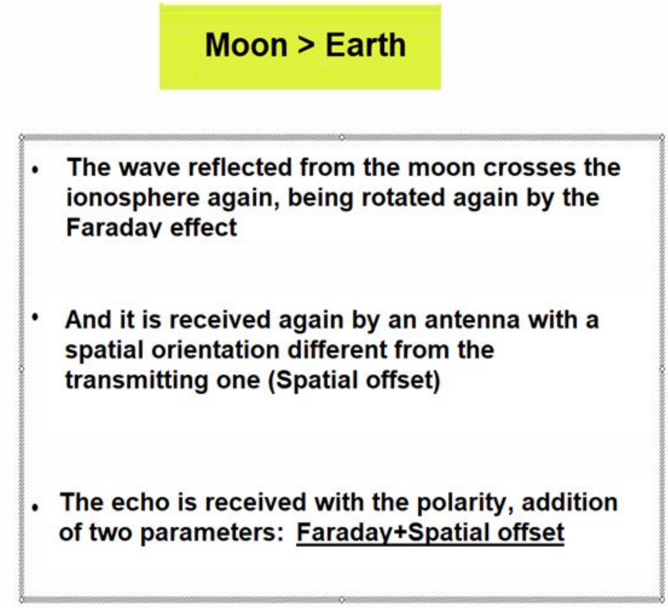


Scattering area in the Lunar surface

- Moon echoes observed by Trexler (1958): most of the power in the reflected signal arises from scatterers lying near the center of the visible disk.



In the Moon echoes observed by Trexler (1958) most of the power in the reflected signal arises from scatterers lying near the center of the visible disk. From the figure on the right, you can see the type of surface from which the wave is scattered.

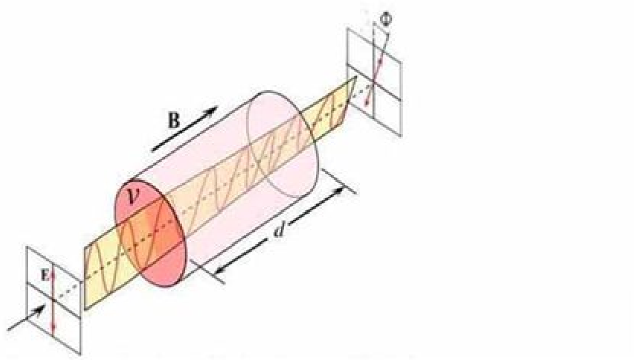


So far, our research has been qualitative.
But we felt the time had come to move on to quantitative investigations. We wanted to quantify these rotations, and since most EME stations, especially in 2 meters, use single-polarization antennas, we wanted to investigate the conditions of reception. To represent a QSO between two stations you need data, reciprocal positions, state of the ionosphere above them, and their "spatial offset".

The search for these data has been illustrated in our other presentations (EME World Conferences in Italy and the Netherlands), of which we move on to insert slides in this diary.

Rotation: Faraday effect

In 1895 Faraday discovered that the polarization plane of a linearly polarized wave, as it passes through a medium, can be rotated by the application of an external magnetic field aligned with the direction of movement of the wave.



An electromagnetic wave passing through the ionosphere will rotate of:

$$\Phi = k * B * TEC / f^2 \text{ (rad), where:}$$

B = component of the magnetic field in the direction of the moon

TEC = **T**otal **E**lectron **C**ontent of the mean

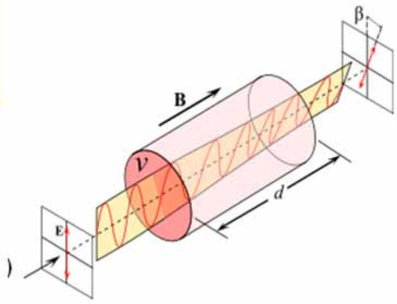
f = wave frequency

$k = 2.36 \times 10^{16}$

Faraday rotation is proportional to the magnetic field component and to the amount of plasma traversed. The formula gives the average rotation value, since the ionosphere is turbulent, which cause short term variations of plasma density. The turbulence is also the cause of short term QSB.

The coefficient of the formula contains the inverse square of the frequency.
So, it decreases to about 1/9 for each successive band.

Faraday rotation



Geomag. field — Electron content

□$\Phi = k/f^2 \; * \; F*\cos FM \; * \; k_s*VTEC$

- $k = 2{,}36*10^{16}$

f =	50 MHz	144 MHz	432 MHz	1296 MHz
k/f^2 =	**9,46**	**1,14**	**0,127**	**0,012**

G

Who is affected by Faraday?

$$\Phi = k * B * TEC / f^2$$

- **It is inversely proportional to the square of the frequency**
- **With the same B and TEC we have:**

Frequency:	Rotation (°) :			
50MHz	90°	360°	810°	9 giri
144 MHz	10°	40°	90°	360°
432 MHz	1°,1	4°,5	10°	40°
1296 MHz	0°,1	0°,5	1°,1	4°,4

- So it only affects the VHF frequency
- In micro waves only the Spatial Offset must be taken into account

We have been looking for sources for these factors:

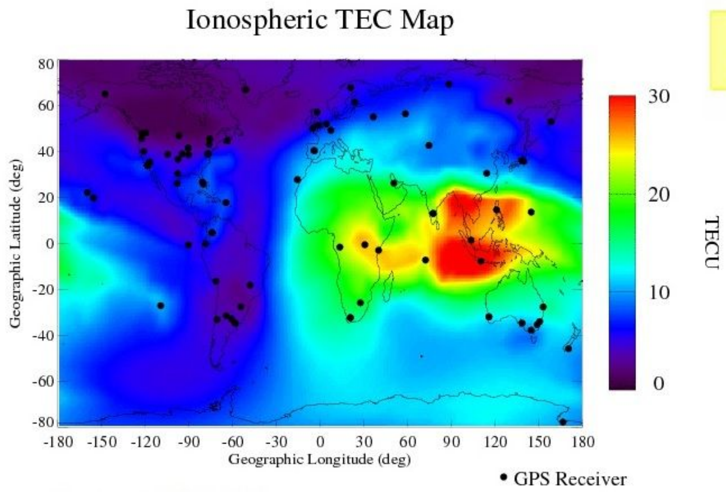
- TEC (total electron content of the ionosphere above stations)
- B (component of the geomagnetic field in the direction of the moon

TEC (Total Electron Content)

$$\Phi = k * B * TEC / f^2$$

The TEC (Total electron content) is a key descriptive parameter of the ionosphere. Represents the total number of electrons present along a path between two points, measured in number of electrons per square meter with: **1 TEC unit (TECU) = 10^{16} elettroni/m^2.**

- **The TEC provides us with the measurement of the number of electrons contained in a 1 square meter base cylinder and height equal to the path taken into consideration**
- **It is an integrated measure that depends on the path between us and the satellite**



1 TECU) = 10^{16} elettroni/m^2

Image public domain (Wikipedia)

How do they measure TEC

The TEC measurement can be obtained by comparing the behavior of 2 frequencies emitted by the satellite that travel the same path, but undergo different phase delays

- The TEC measurement is made by measuring the phase difference between the two signals L1 and L2

- The measurement of the TEC depends on the path made by the signal, therefore the direct measurement, gives the TEC along the path from the RX to the satellite

In reality, what you would like to know is the TEC on the vertical of the receiver: Taking the direct measurement makes an error (the greater the lower the satellite is on the horizon). The problem of the passage from the slant TEC, (STEC), then, with a mathematical algorithm, this value is converted into VTEC (vertical TEC), which is the value that interests us to calculate Faraday

The VTEC diagrams

The calculated value of the VTEC electronic content is provided by a series of research organizations present on the web

We have chosen to work with the **ROYAL OBSERVATORY OF BELGIUM (ROB)** in Dourbes. As it publishes very detailed graphs on VTEC, they have a searchable archive by date

Thickness of the ionosphere (Slab thickness)

G

- **The ionosphere is not measurable with a number, its density varies with altitude**

A wave that crosses vertically encounters increasing electron densities, then after a maximum density (peak F2), it decreases. To derive the total content of N electrons encountered, it is sufficient to make an integral of the density curve, or to find an equivalent rectangular area (bold rectangle)

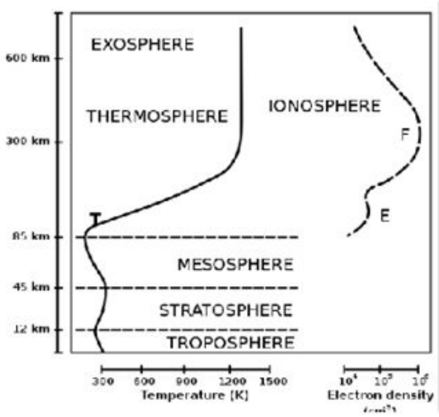


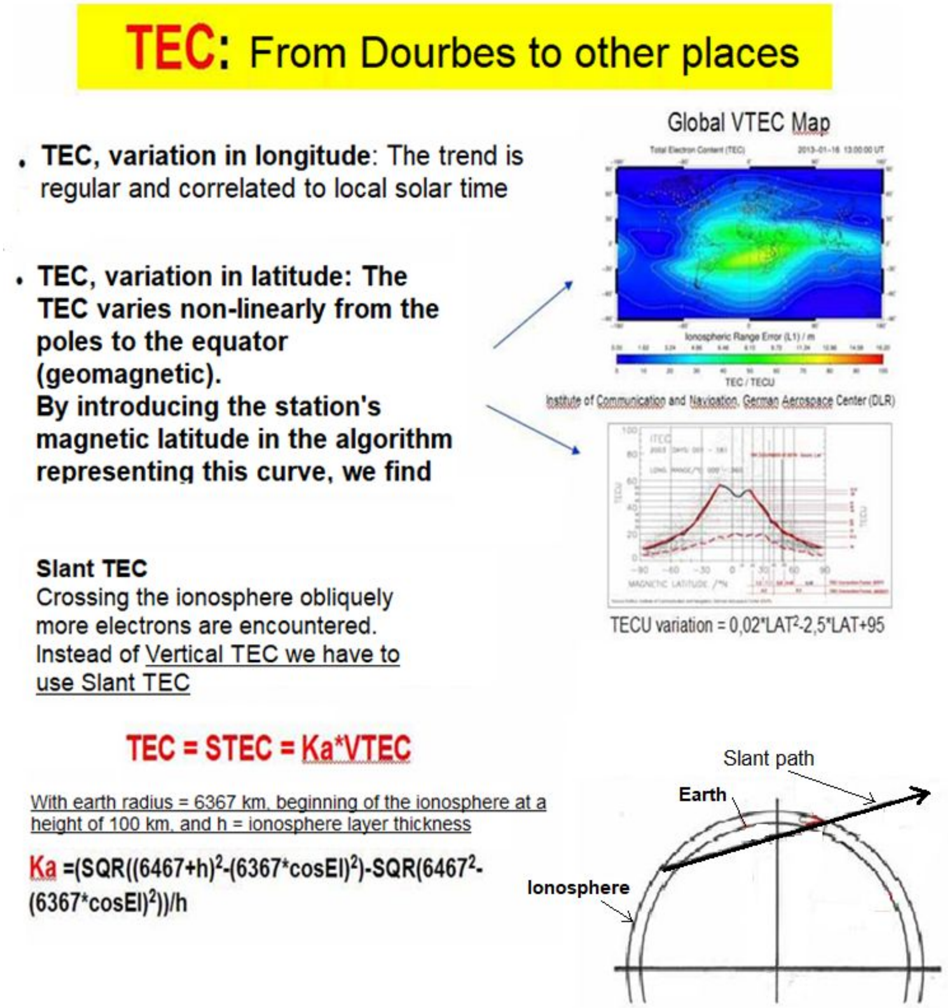
Fig. Schematic electron density profile.
(Image: Wikipedia - Public domain)

Il rettangolo ha altezza h=275 km e larghezza $1*10^6$ elettroni/cm^3=$1*10^{12}$ elettroni/m^3
Una colonna di sezione 1 m^2, lunga 275 km, ha un contenuto di elettroni (elettr.*m/m^3=elettr./m^2)
$N = 1*10^{12}*275*10^3 = 27,5*10^{16} =$ 27,5 TECU

The choice of the rectangle is completely arbitrary, it just has to have the same area as the density curve. Dourbes chose to use the peak value F2, hence the slab tickness h = 275 km

With just two numbers, an effective and simple schematization of the ionosphere was created

We have a quantization of the ionosphere, as a function of time, above Dourbes in Belgium. We need to turn this data for the location of the two stations into QSO.

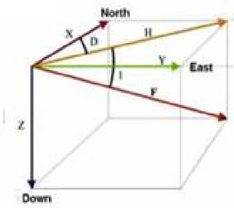


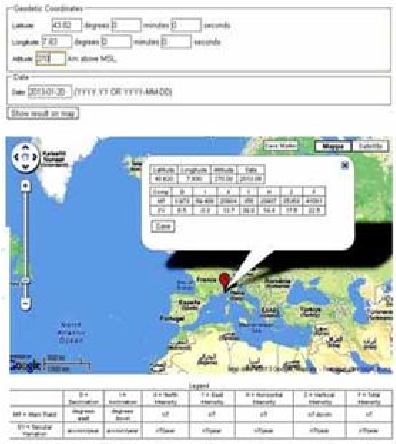
It is reasonable to assume that the hourly variation of the ionosphere is the same in other positions on earth on the same day. Then, for longitudinal variation, just use the local time of the stations.
For latitude variation we will use the Ka coefficient that can be obtained from the equation.

$$\Phi = k * B * TEC / f^2$$

- From the British Geological Survey website, introducing the station's Latitude and Longitude, the average height of the ionosphere and the date, we have:

- Total magnetic field F (in Tesla)
- Inclination I (°)
- Declination D (°)
- Geomagnetic latitude





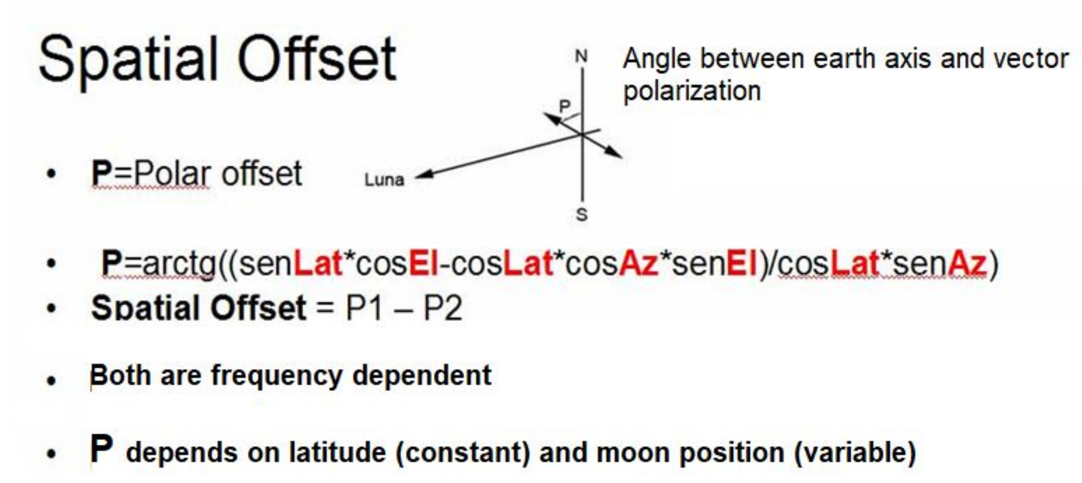
We need B, that is the component of the magnetic field in the direction of the moon

Vector F is defined by inclination and declination
moon vector is defined by Azimuth and Elevation.
To project the F field onto the moon's direction, we need the FM angle between these two vectors. Formula:

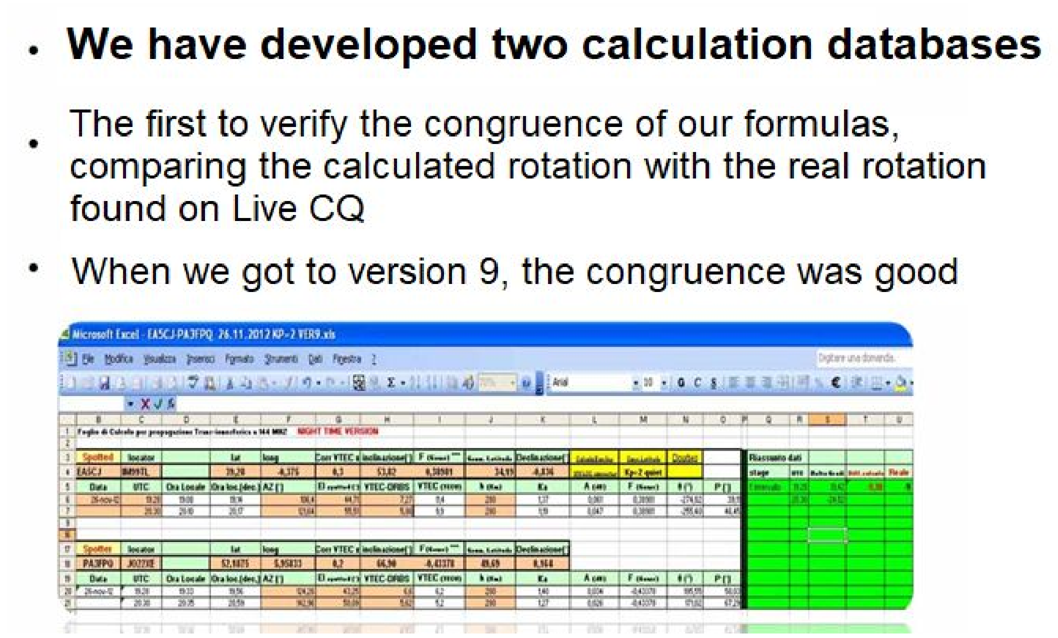
cosFM=cosI*cosD*cosEL*cosAz+cosI*sinD*cosEl*sinAz-sinI*sinEl

$$B = F * \cos FM$$

FM is the angle in space of the two vectors direction Moon and field direction F.
We've completed finding sources of Faraday-related factors.
Let us see the other factor that enters the rotation equation, spatial offset (S.O. from here on out).



We are finally able to do calculations for pairs of stations extracted from our database.



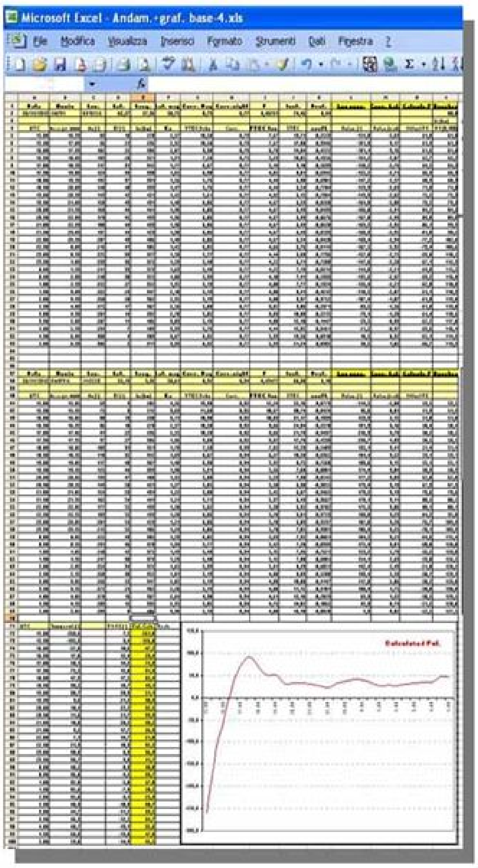
We have developed a second, more comprehensive sheet that covers a whole lunar day.

Our tools

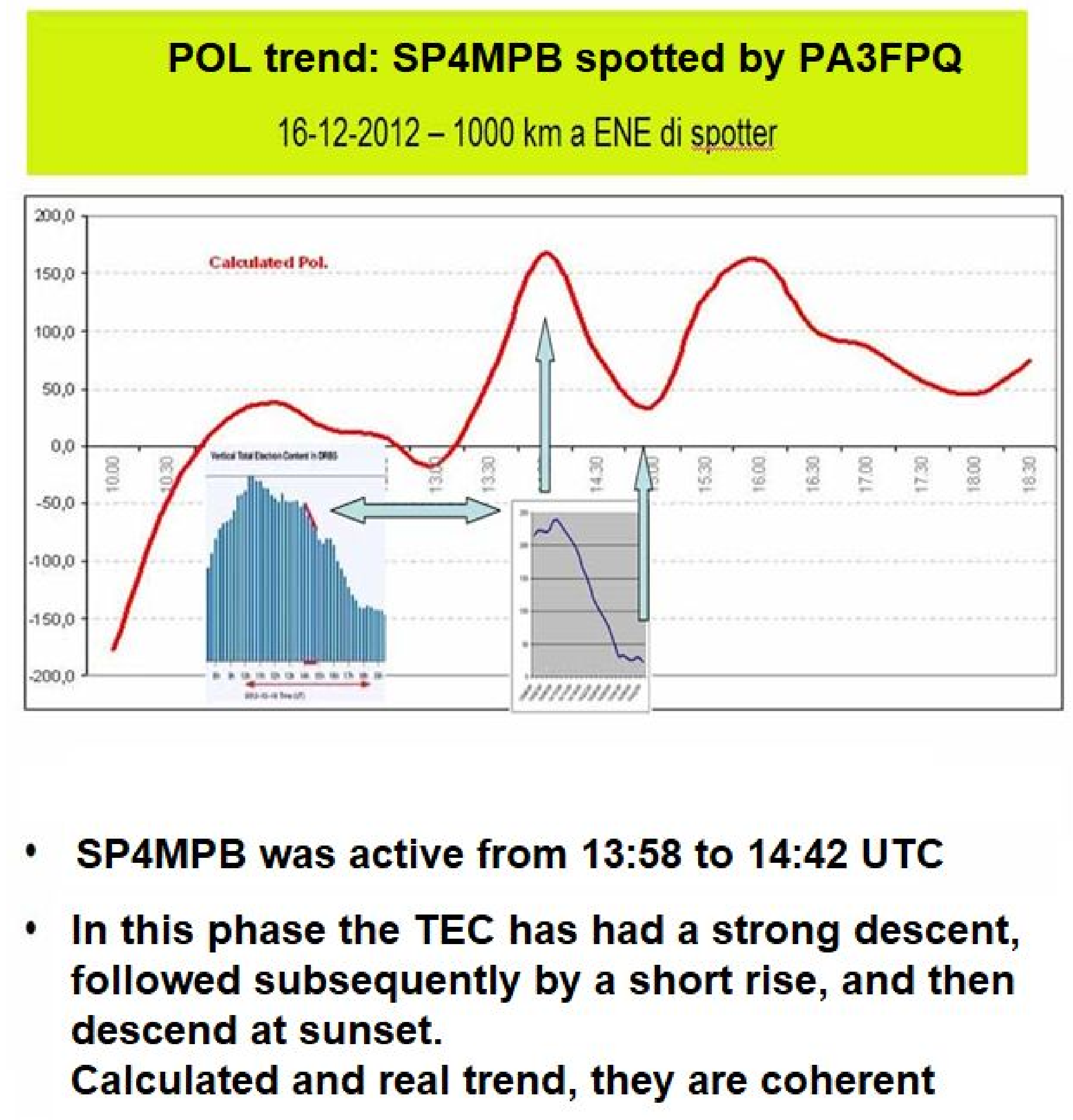
- The second, with the tested formulas, covers an entire lunar day, thus giving a broad spectrum version of the polarization trend

- Also in this case, the calculated trend was found to be consistent with the real trend

- We show some cases



For brevity we show only one verification, but significant.

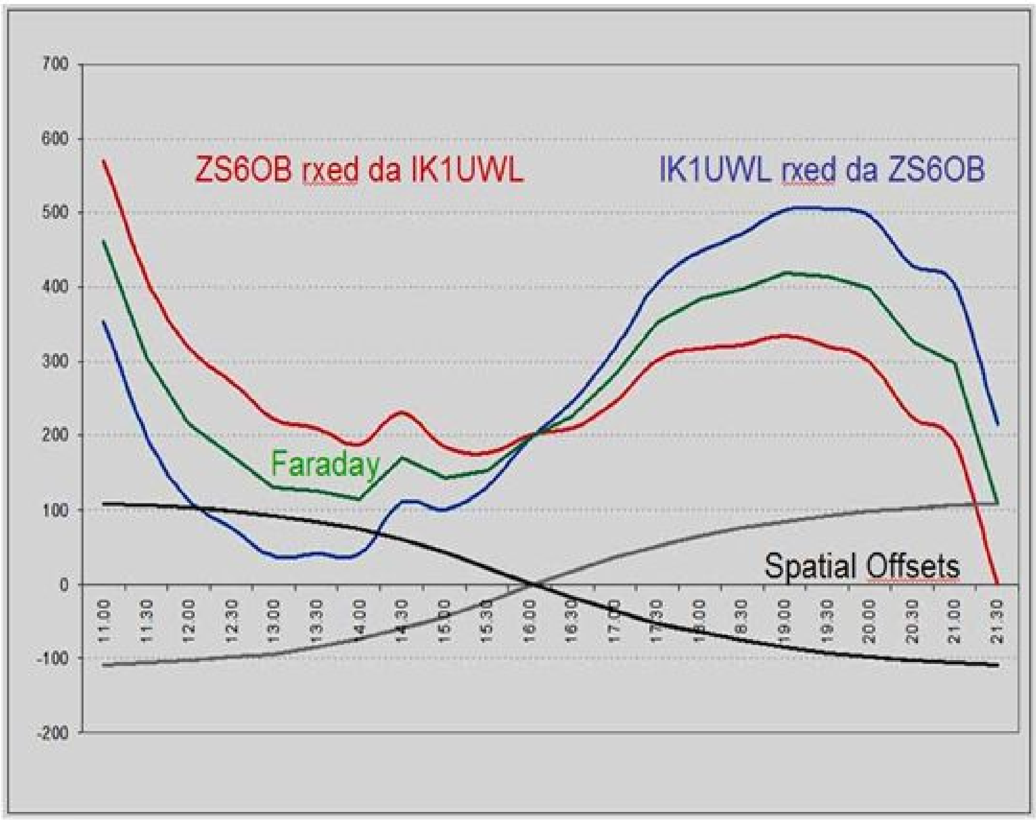


The trend in a whole lunar day

So far, we have only calculated the evolution of the polarization of one station received from another station, i.e., half of a potential QSO between them.

Now let us proceed to examine an entire QSO and decodability, not always reciprocal, if the stations have linear polarization antennas.

QSO ZS6OB – IK1UWL in 144 MHz



- **Faraday + each Spatial Offset = each polarity**

The green curve referred to as "Faraday" is the trend of the Faraday effect rotation for both stations.
To this rotation must be added the Spatial Offset (the two black curves at the bottom) which are opposite for the two stations. For station 1 it is P1-P2. For station 2 it is P2-P1 i.e. –(P1-P2).

So, they will be mutually vertical several times, at different times. Let us say IK1UWL has horizontal antennas only and let us see the respective decoding.

QSO- Non-decoding zone for single polarity antennas

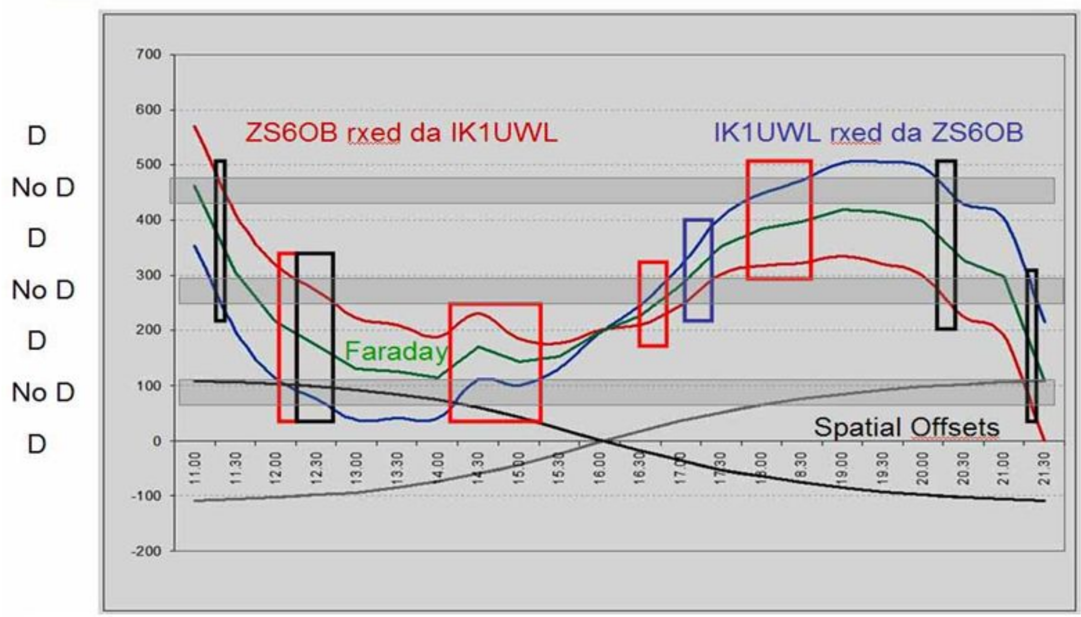
- Polarity α has degradation $= 20 * \log \cos \alpha$ (dB)

- $\alpha = 45°$ Degr. 3 dB
- $\alpha = 60°$ " 6 dB
- $\alpha = 75°$ " 12 dB
- $\alpha = 90°$ " >20 dB (causes depolarization)

- With crossed Yagis, after 45 ° it is useful to switch to Vertical polarization

- With linear antennas, polarity between 75 ° and 105 ° have low probability of decoding

QSO ZS6OB – IK1UWL in 144 MHz



- **Frequent "Not decoded" and "one way", bilateral decoding 66% of the moon pass**

In band 144 MHz, Faraday varies quickly, so the periods holes, are usually of the order of half an hour. In the upper bands, spatial offset begins to become more important than Faraday, which is inversely proportional to the square of the frequency.

□ $\Phi = k/f^2 * F*\cos FM * k_s*VTEC$

- $k = 2{,}36*10^{16}$

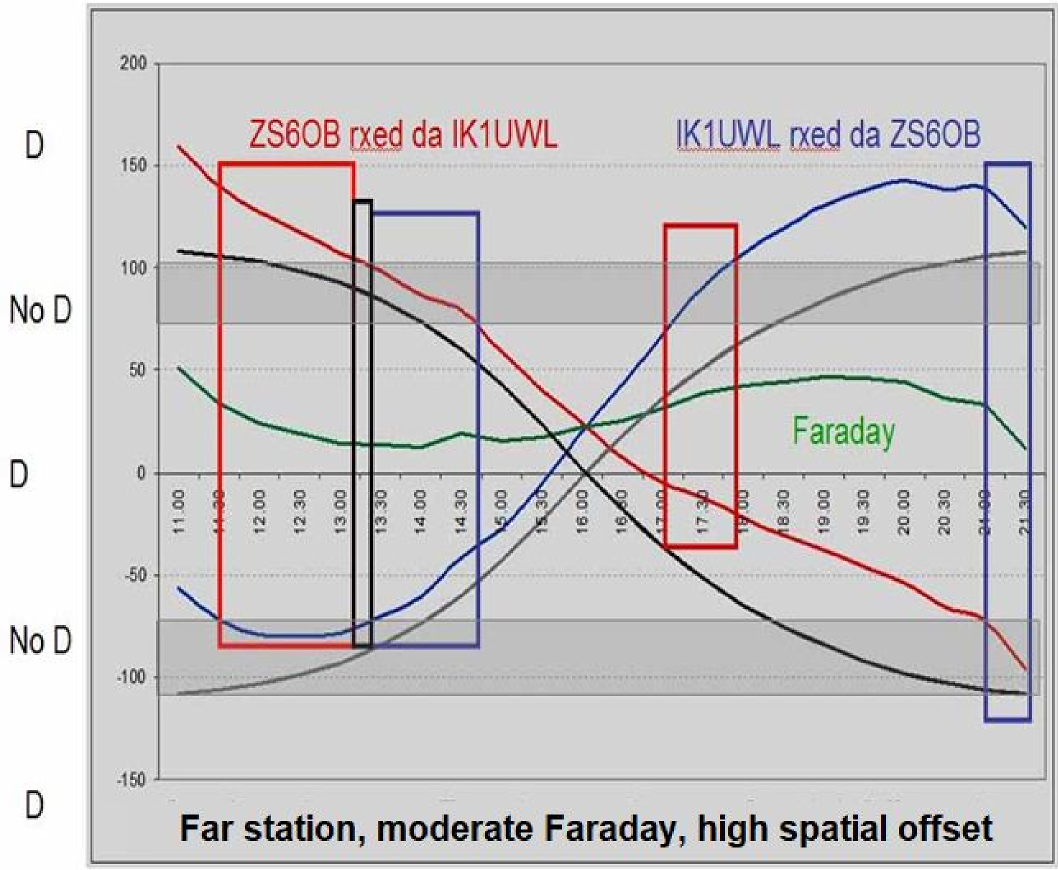
F =	50 MHz	144 MHz	432 MHz	1296 MHz
k/f2 =	**9,46**	**1,14**	**0,127**	**0,012**

- **This coefficient results in rotations of thousands of degrees at 50 MHz, hundreds at 144 MHz, tens at 432 MHz**

- **Rotation at 432 MHz is secondary to Spatial Offset, and is negligible at 1296 MHz and beyond**

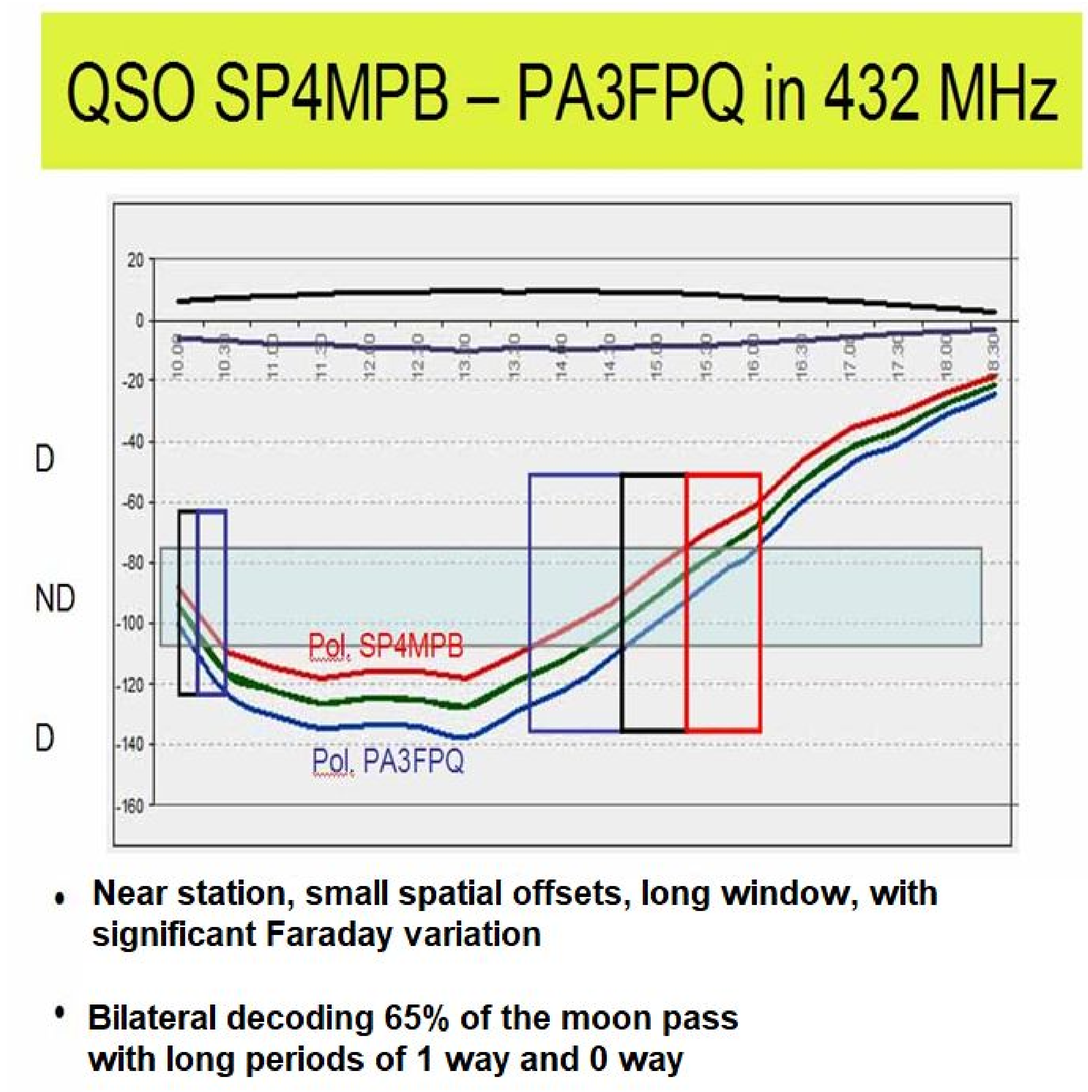
We simulate the same QSO in the upper bands:

QSO ZS6OB – IK1UWL in 432 MHz



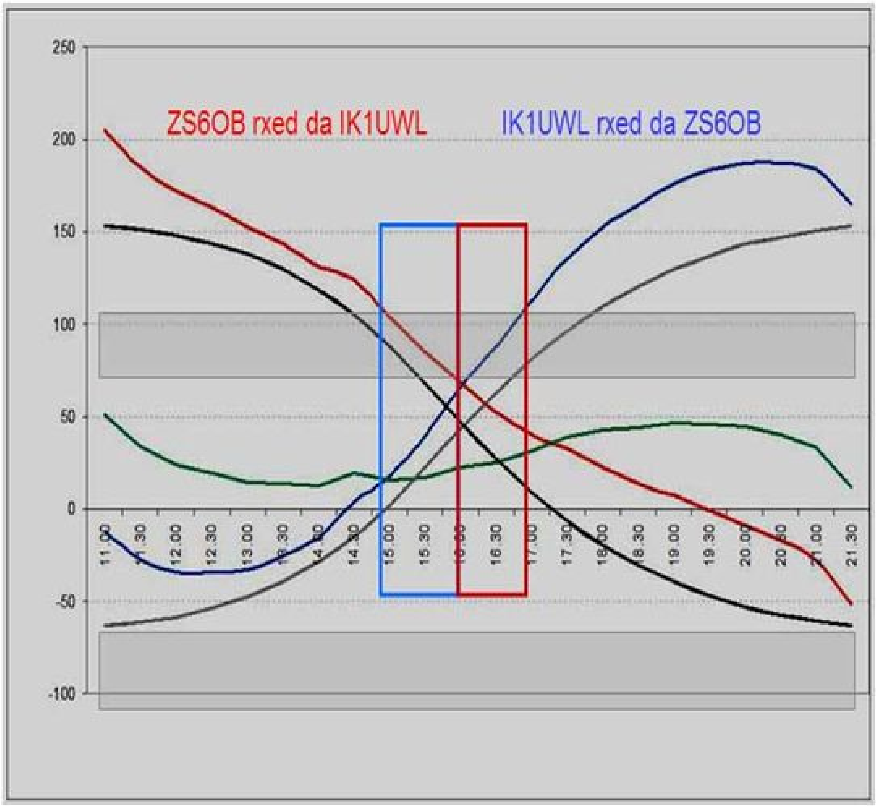
- **Few bilateral periods, 56% of the moon pass**

Faraday's rotation is contained in about 50°, the S.O. exceeds 100° and conditions a long period of non-decodability. Since the S.O. is much smaller for nearby stations, we simulate a qso between SP4MPB and PA3FPQ that are 1000 km away



In this case it is conditioning Faraday, also the low rate of variation of both Faraday and S.O. makes the signals remain for a long time in conditions of non-decoding.
In this band, rotations of the Yagi are used to modify the S.O. and move the conditions of non-decoding. Here is what would happen if ZS6OB rotated the Yagi even just 45°.

QSO in 432, ZS6OB rotate the Yagis **45°**

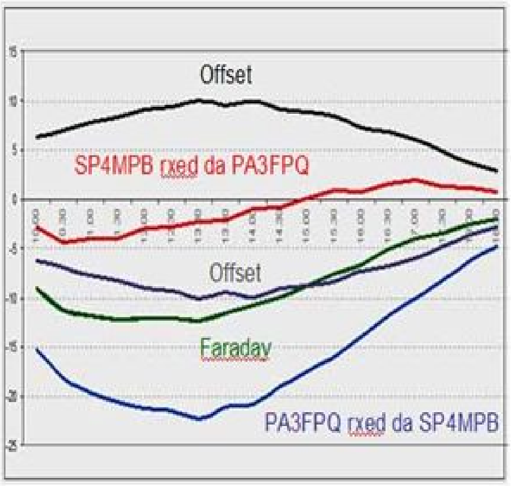


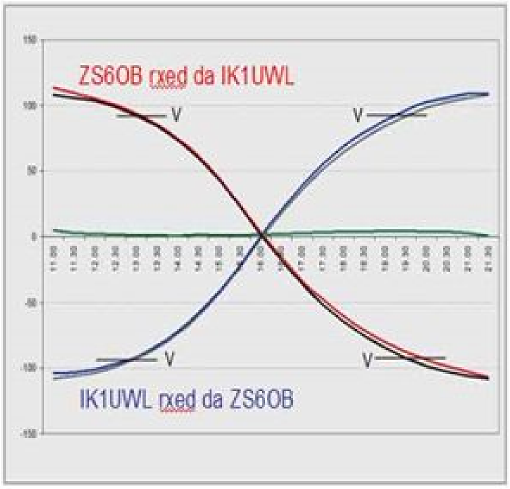
- **The variation of the spatial offset brings only 20% of the lunar day, in no decode condition at different times**

Switching between conditions would achieve decodability throughout the lunar day. Often DX expeditions that also work on 432 MHz, gear up to do this.
Let us look at the situation in 23 cm.

UHF, banda 1296 MHz Ts 68 °K

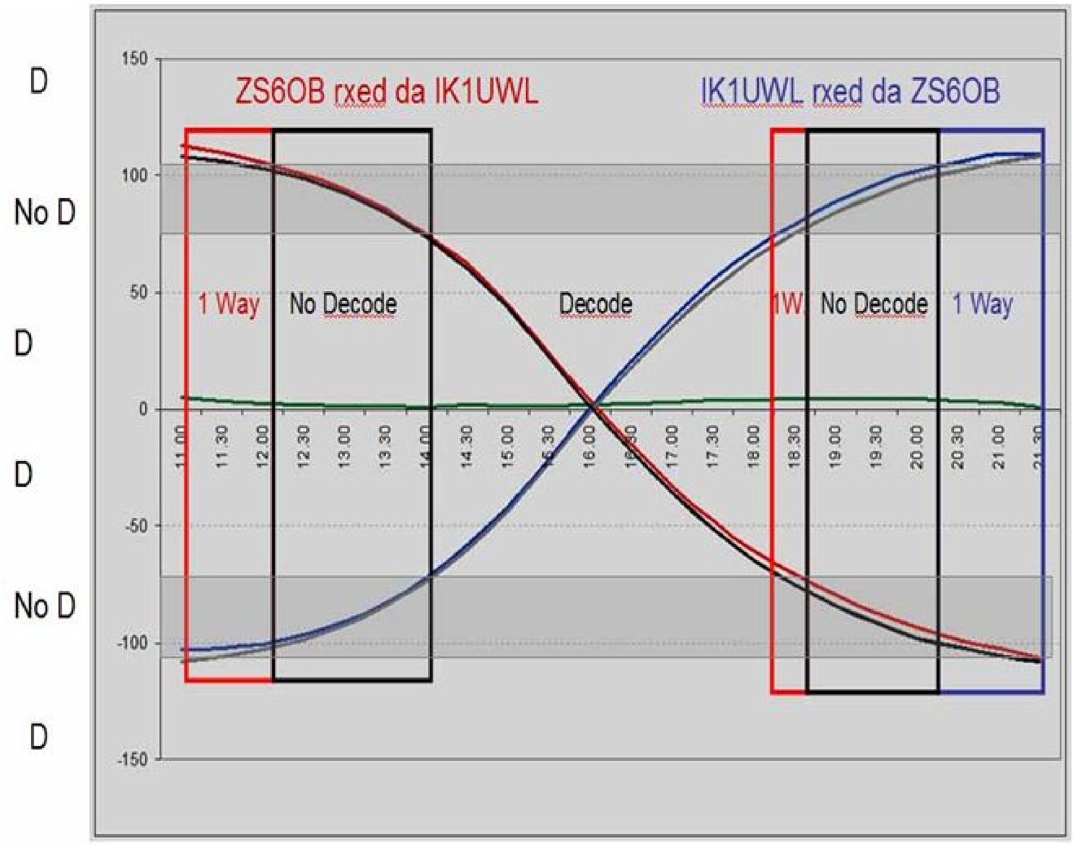
Near station 1000 km | **station 8000 km away**





- **Faraday rotates only a few degrees**
- **Spatial offset becomes the dominant factor**
- **With low spatial offset decoding on 100% of the moon pass**
- **Problems with increasing distance: let's analyze the QSO**

QSO ZS6OB – IK1UWL in 1296 MHz



- **Bilateral decoding only 40% of the moon pass**

That is why in this band there is a prevalent use of parables with illuminators that make circular polarization.

Conclusions

- VHF are dominated by Farady
- The UHF and higher from the Spatial Offset
- Spatial Offset is not a constant, but varies during the moon pass, with distance and declination
- With increasing frequency the polarity varies more slowly, from 1000 ° / h on 50 MHz to 10 ° / h on 1296 MHz
- With single polarity antenna, the periods favorable to QSO decrease in number, the odd ones increase in duration
- At 432 MHz variable polarity is useful
- At 1296 MHz it is convenient circular polarization and it is used

EME with a single Yagi in 144 MHz

The connections between radio amateur stations via the Moon, have always required very sophisticated stations and above all high-gain antenna systems, obtainable only with configurations of several coupled directives antenna. In fact, the earth–Moon–earth path of over 700,000 km, the great attenuation of the path and the poor reflection capacity of the lunar surface (in 144 MHz only about 7% of the energy is reflected by the moon) and the variability of propagation conditions represent a difficult obstacle. The digital transmission system designed and developed by Joe Taylor, K1JT, Nobel Prize in Physics in 1993, revolutionized the world of EME transmissions and paved the way for normal stations as well. In fact, Joe Taylor's program has opened a new era in amateur radio communications via the Moon. Using WSJT software in JT65B mode it is possible to do QSO via the moon even with a single Yagi antenna and 100 watts of power. The greatest chances are when the lunar orbit is at the perigee (the closest point to the Earth) and when the sky noise temperature is lower.

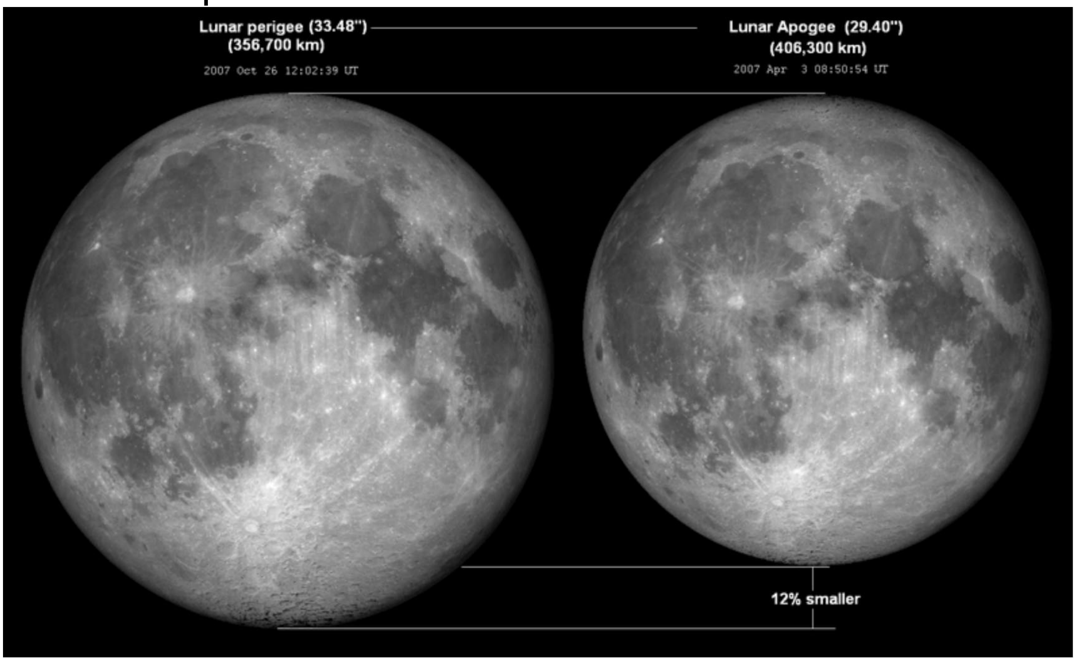


Fig. The Moon travels a slightly elliptical orbit in 28 days, the closest point to the earth the perigee (356,700 km) and the farthest apogee point (406,700 km). Path losses are of -251.5 dB at perigee and -253.5 dB at the apogee. The signal delay is about 2.4 sec and 2.7, respectively. WSJT, if both stations are properly synchronized, can detect it with good accuracy. The figure at the top shows what the moon looks like observed by the earth at its farthest and closest point. when it is at the perigee it appears about 12% larger), this results in about 2 dB of path loss difference (on 144 MHz).

Image credits: Source: Transferred from Wikipedia to Commons by Mike Peel using Commons Helper.
Author: The original uploader was Tomruen at English Wikipedia.

Noise

One of the most important things in the development of the station is the care of the receiving section trying to reduce as much as possible the level of noise received or the signal-to-noise ratio S/N. Even a few decibels can make the difference between hearing and not hearing the lunar echo. The best thing is to use antennas as quiet as possible with excellent quality preamplifiers with a noise figure not exceeding 1 decibel. Galactic noise is always present, although it varies periodically at the lunar movement. The most difficult noise to handle is urban noise. For EME communications a low level of background noise makes the difference, it is fundamental, and even more so for those who operate with low power and small antennas, reduce it as much as possible by taking all precautions (low loss cable, antenna with narrow through band, etc.). In this context, WSJT software provides a significant help. You can extract and decode signals from noise up to -29 dB, but if you improve the signal to noise ratio level, even a few decibels can be decisive and the difference is between hearing a station and not hearing it at all.

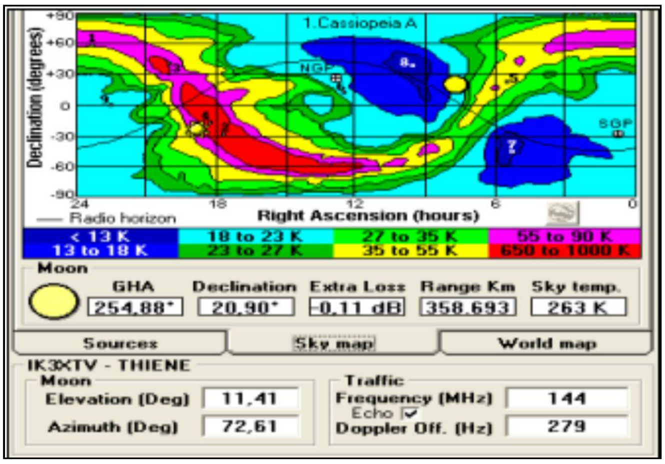


Fig. Map of the sky with the various noise temperatures. The diagram above shows our galaxy, the Milky Way. The sine line represents the plane of the elliptical. The sun makes a path along the elliptical in a year. The moon moves along the elliptical line (+/- 5°) every month when the moon passes in the direction of the sun, heme activity is difficult because of the high cosmic background *noise (red zone). This occurs periodically in the new moon phase. (Image created with EME System Software by F1EHN).*

Ground Gain

Working on the moon rise or moon set, (i.e., from 1 to 18/20 degrees elevation) you can take advantage of the ground effect or an additional gain that theoretically can reach 6 dB, it means that a single Yagi gets the performance of an array of 4 Yagi. The ground gain, however, depends on the type of terrain around the antenna, for those like me who operate from the city center, this value is certainly lower. For those who work in the open countryside or better still near the sea, things improve markedly. Without elevation it is possible to acquire the moon from 0 degrees to about 18/20 degrees of elevation, thus working on the moonrise and moonset you have about 3 hours a day.

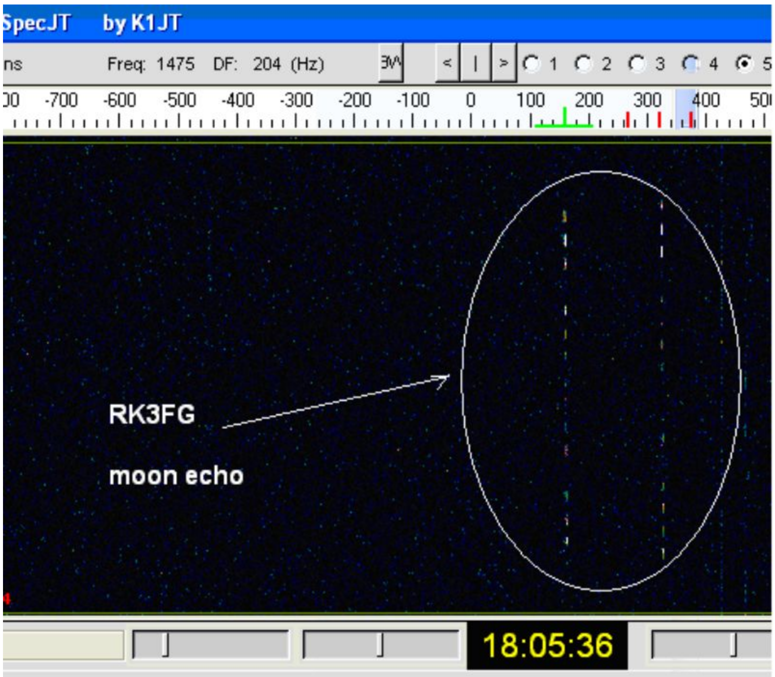
Additional factors influencing propagation

Ground gain alone is not enough to explain the feasibility of some moon connections with QRP stations. There must be some additional and currently unknow factor that increases and amplifies the signal. The heme signal must twice cross the Earth's ionosphere, with quite different portions of the ionosphere. Due to this transit, it undergoes the rotation of Faraday, which introduces a phase shift that often does not allow reception. But we do not know whether, for example, this ionospheric step can at certain times introduce favorable action. On the "Moon side" we know that not the entire surface of the satellite has the same characteristics of reflection and in any case the reflection takes place completely in the center of the visible disk. On the earth side, on the other hand, there are numerous factors that can get worse and why not, at certain times increase the signals: not only the ionosphere but the Earth's magnetic field and with it the magnetosphere that approaches as dimensions to the lunar orbit. I believe the Earth's magnetosphere can play a non-secondary role in the dynamics of earth-moon-earth propagation. For smaller stations, it is easier to access stations within the same continent: EU-EU. This is due to the lower spatial angle between stations when they are close. Think of the earth-moon-earth angle that connects, for example, two stations on different continents, the radius of reflection incidence on the moon can differ by up to 2 degrees. This has an impact on both the earth side (ionosphere) and the moon side as it can change the angle of incidence on the lunar soil and thus affect the quality of the reflected signal. The best hours to operate are at night, as the noise is lower and the ionospheric attenuation is lower, in 144 MHz it is worth about 0.5 dB, this value at night is about 10 times lower.

WSJT JT65B mode for EME communications

The software created by Joe Taylor specifically for EME communications that can decode signals many decibels below the noise threshold, and extract from background noise signals that are inaudible from the human ear. The messages are transmitted digitally, without going into technical detail (the manual in Italian can be downloaded from the official website of wsjt) the data is compressed and then encoded with an error correction algorithm (FEC) that introduces redundant control over the data, so that all parts of the message can be successfully retrieved, even if some parts of the message are not received by the receiver. The message consists of 72 bits for user information, and 15 bits for the lessor. (The code used for JT65 is Reed Salomon.) After the messages have been encoded, they are transmitted using MFSK in 65 tones, (the busy bandwidth is 170 Hz) and a transmission period of 50 sec, after which it passes into reception and so on. In reception, the received signal is analyzed according to the Fourier transform which is a specific mathematical procedure for data analysis. JT65 requires your computer to be synchronized with an NTP internet server for proper message decoding to keep the pc time accurate at all. Wsjt provides various modes of transmission, some still experimental, the way used for EME communications is the JT65B.

EME Test Configuration
-YAGI antenna 13 elements (3.5WL) 13 dBd.
-Solid state power amplifier (no. 2 MRF245 push-pull) max output 150. Power used in JT65 mode. 100w. - Gasfet preamplifier 23 dB gain NF=0.5 dB -Rtx Kenwood TS711E.
-Digital sound processor (used to reduce noise level as much as possible).


SpecJT by K1JT
Freq: 1475 DF: 204 (Hz)
RK3FG
moon echo
18:05:36

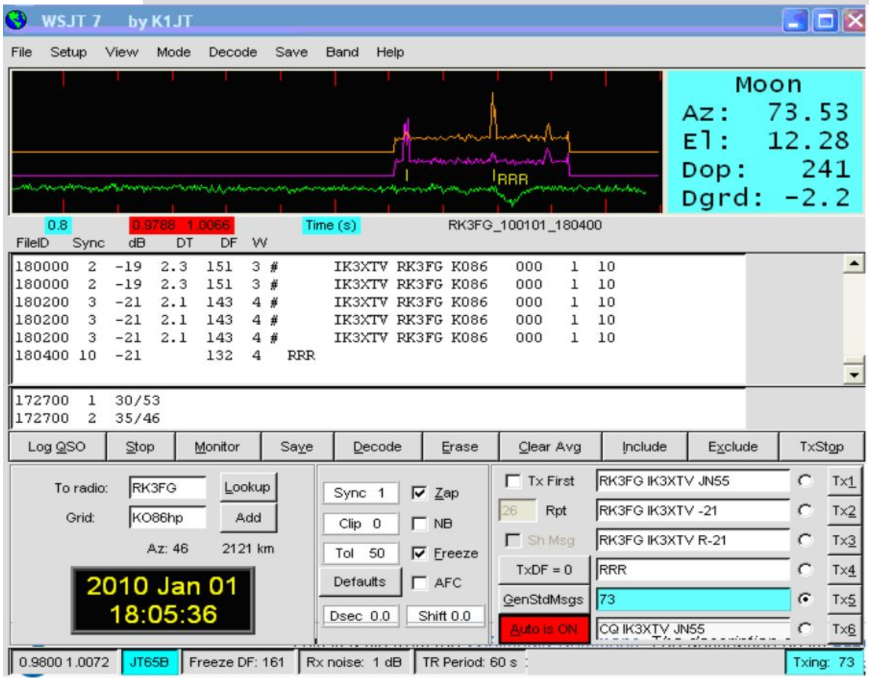

WSJT 7 by K1JT
File Setup View Mode Decode Save Band Help
Moon
Az: 73.53
El: 12.28
Dop: 241
Dgrd: -2.2
RRR
RK3FG_100101_180400
FileID Sync dB DT DF W
180000 2 -19 2.3 151 3 # IK3XTV RK3FG KO86 000 1 10
180000 2 -19 2.3 151 3 # IK3XTV RK3FG KO86 000 1 10
180200 3 -21 2.1 143 4 # IK3XTV RK3FG KO86 000 1 10
180200 3 -21 2.1 143 4 # IK3XTV RK3FG KO86 000 1 10
180200 3 -21 2.1 143 4 # IK3XTV RK3FG KO86 000 1 10
180400 10 -21 132 4 RRR
172700 1 30/53
172700 2 35/46
Log QSO Stop Monitor Save Decode Erase Clear Avg Include Exclude TxStop
To radio: RK3FG Lookup
Grid: KO86hp Add
Az: 46 2121 km
2010 Jan 01
18:05:36
Sync 1 Zap
Clip 0 NB
Tol 50 Freeze
Defaults AFC
Dsec 0.0 Shift 0.0
Tx First
Rpt
Sh Msg
TxDF = 0
GenStdMsgs
Auto is ON
RK3FG IK3XTV JN55 Tx1
RK3FG IK3XTV -21 Tx2
RK3FG IK3XTV R-21 Tx3
RRR Tx4
73 Tx5
CQ IK3XTV JN55 Tx6
0.9800 1.0072 JT65B Freeze DF: 161 Rx noise: 1 dB TR Period: 60 s Txing: 73

Fig. Screen shot of the EME QSO of 01.01.2010 with RK3FG (4x15 elements) with good conditions, Moon at perigee and low cosmic noise temperature.

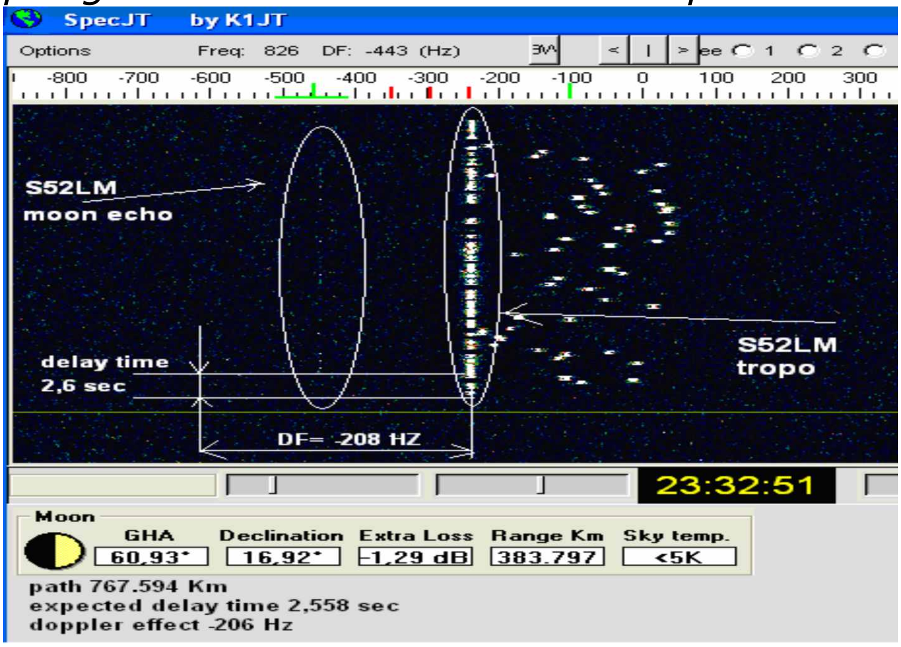


Fig. Tropospheric and EME reception experiment with S52LM (4x17 1.5 kW) The differences and characteristics of the echo received via the moon are highlighted. The wsjt software recorded a delay time of 2.6 sec. (The calculation for DT with the distant moon 383,797 km away is DT= d/c where d is the earth-moon-earth path and c the light speed *DT=767.594 /* 299 792.458=2.56 sec) *with a frequency shift of -208 Hz. The tropospheric signal is at -7 dB while the moon track at -26 db. The test was done with the moon at sunset when the moon signals are afflicted by a negative doppler, while at moonrise, due to the doppler effect between the earth and the moon, the shift is positive.*

QSO EME QRP

Thanks to Franco, I2FAK and its fantastic EME array consisting of 16 Yagi of 19 elements, they are designed and made by Giampaolo I3DLI. I did an incredibly good EME QSO with only 20 watts of power and with two YAGI antennas of 8 elements, coupled horizontally. Something of incredible, but still possible. I post the WSJT screen shot, where you can see the trace of the I2FAK EME signal, which sends me confirmation that He have received my transmission. This experiment prompted me to do more tests, trying to further reduce the transmitting power.

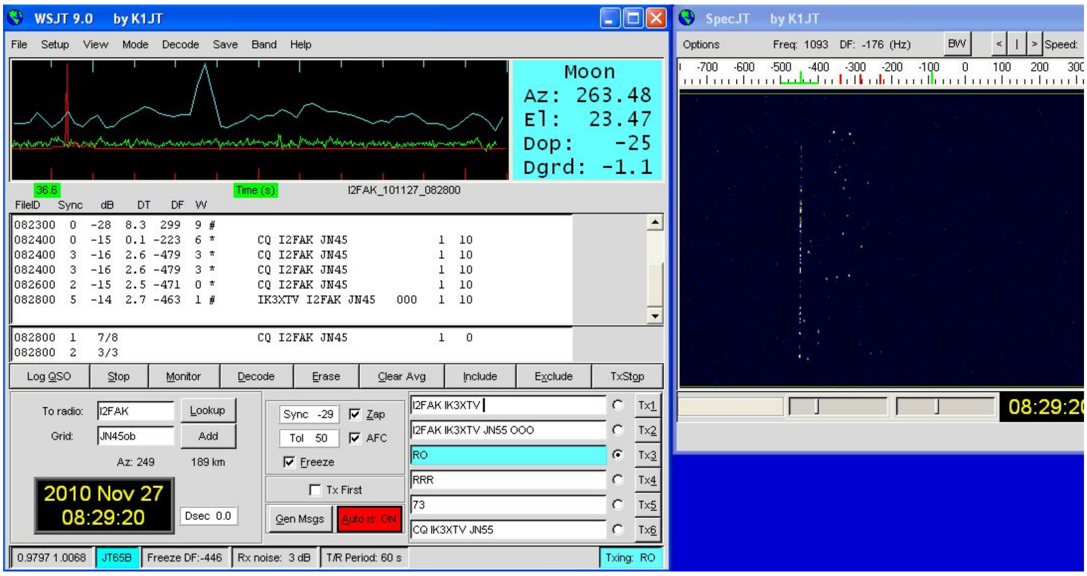


Fig. QSO EME QRP that I did with I2FAK, November 27, 2010, at 08:29 UTC.

EME: Beyond the impossible

A radio amateur is always looking for new challenges. After the success of the attempt did at the end of November 2010 with only 20 watts, I tried to raise the bar again. The

occasion came on the afternoon of January 5, 2011. I saw on the EME chat that Franco, I2FAK was calling CQ EME on the frequency of 144,125 MHz. I tuned on my Kenwood and I set the power trimmer to a minimum. The minimum power of the TS711E is only 2 watts. I tried the impossible and that time the impossible happened. Come says an Arabic proverb: " Don’t *give up. You'd risk doing it just an hour before the miracle.* I did not give up. I remembered Fred Schnell and Leon Deloy, the first OMs to establish a transatlantic QSO, they tried all night. I kept calling repeatedly, I also had little time as the moon was setting down and would soon fall below the horizon. I trusted in Franco's ability and in his great antennas array. These factors can help the miracle. My surprise was enormous when I saw the three OOO appear on the screen of my computer, which meant that he had received my message. I saw them clearly on the screen. My surprise was enormous, I was almost incredulous, so much so that I went to check the position of the power trimmer, it was at minimum! It was true, I was sending 2 watt of power signal to the moon. At 4:38 p.m., I can complete the QSO, when I see the RRR appear on the screen. After the QSO, Franco chatted to me the following string confirming that he had managed to decode my message to -28 dB below the noise level, very weak but still had received it. *So, I2FAK wrote on the EME Chat:*

<u>IK3XTV Flavio, this is the decode: 163300 3 -28 2.5 105 0 * I2FAK IK3XTV 1 0</u>

Franco sent me a decoding report at a level of -28 dB and a DT (delay time) of 2.5 seconds, which confirmed without any doubt that the signal was from the Moon. I had managed to complete a bilateral contact via EME with only 2 watts of power obtained by adjusting my Kenwood TS711E to the minimum power. I considered it a remarkable success and a great stroke of luck. I am aware that each of us has a miracle at our disposal, but only one!

In fact, I tried, at other times, to repeat the experiment with I2FAK but without success.

I do some calculations: 10 dB is missing

Before this event, I did several contacts with I2FAK, using a power of 250 W, the best reception ratio I received from him was -21 dB, but in this case, I called him with only 2 W, so 21 dB less of power. However, in that direction of the moon and at that elevation, I calculated a ground gain of about 4 dB, So, my signal was supposed to arrive at -21-21+4= -38 dB. Given the S/N of -28 dB I received from I2FAK, I can establish that “something” earned to my signal about 10 dB.

Grey line focus hypothesis

but where did those 10 dB come from? But where can that help of +10 dB come from? It is difficult to answer this question. I can only formulate hypotheses. When I am in difficulty, I rely on the "law" of Occam's Razor: «All things being equal, the simplest explanation is to be preferred».
In this case, the simplest explanation is a focusing effect on the grey line. I will explain.
At that time, at 16:33 UTC, the moon was setting, it was low on the horizon at about 4 degrees of elevation. I took advantage of the favorable effect of ground gain. But the ground gain alone we saw that it is not enough. Only two antennas of 8 elements, and 2 watts are really few. I try to explain the reasons for that incredible event. Let us see what happens on the grey line. Due to the pressure of solar radiation, the ionosphere and the earth are not two concentric spheres, this fact leads to a continuous deformation of the ionosphere that is highlighted when the sun sets on a meridian (terminator). At this stage, the ionosphere is highly dynamic and undergoes a drastic change of ionization in the transition from day to night. The electron density in layer E decreases by a factor of 200 to 1 and by a factor of about 100 to 1 in F layer. After sunset, D layer quickly disappears. The signal passing through this portion of the ionosphere for a few hundred

kilometers and may encounter oblique surfaces relative to the ground as well as curved surfaces that can give focusing effects. These additional decibels may be arrived from a focusing effect on the grey line, that the wave beam crossed to reach the surface of the Moon. The strange thing is that the I2FAK signal came me less strong than usual, so much so that I also had difficulty decoding it, as if in his case, the grey line degraded his signal.

These are the QSO data: Frequency :144.125 MHz -Date: 05.01.2011 Time: 16.35 UTC
Kp index=0 (Quiet) - IK3XTV Antenna 2x8 elements I0jxx.
Length 4 meters - RTX Kenwood TS711E – LNA Gasfet

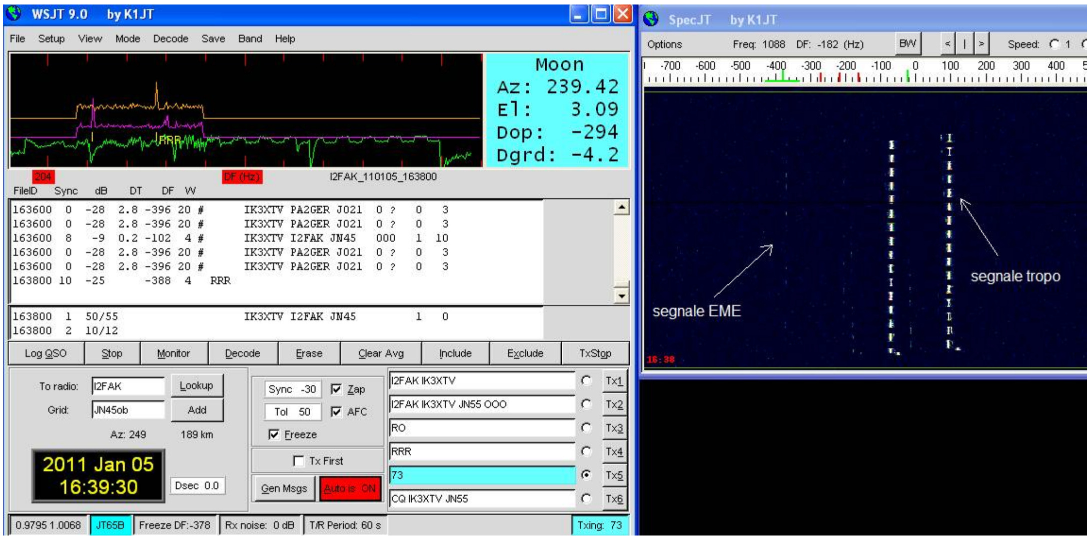
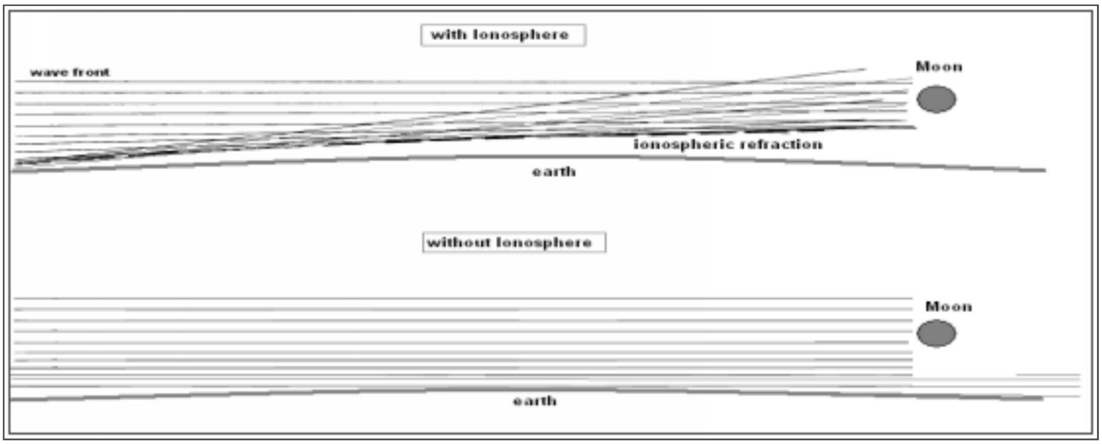


Fig. Screenshot of WSJT with RRR received at 16:38 UTC by I2FAK. In the spectrum on the right side, you can see both tracks, EME and tropo.

YOU HAVE TO BELIEVE IN THE IMPOSSIBLE, BECAUSE THE IMPOSSIBLE CAN HAPPEN”
(HERACLITUS)

“


with Ionosphere
wave front
Moon
ionospheric refraction
earth
without Ionosphere
Moon
earth

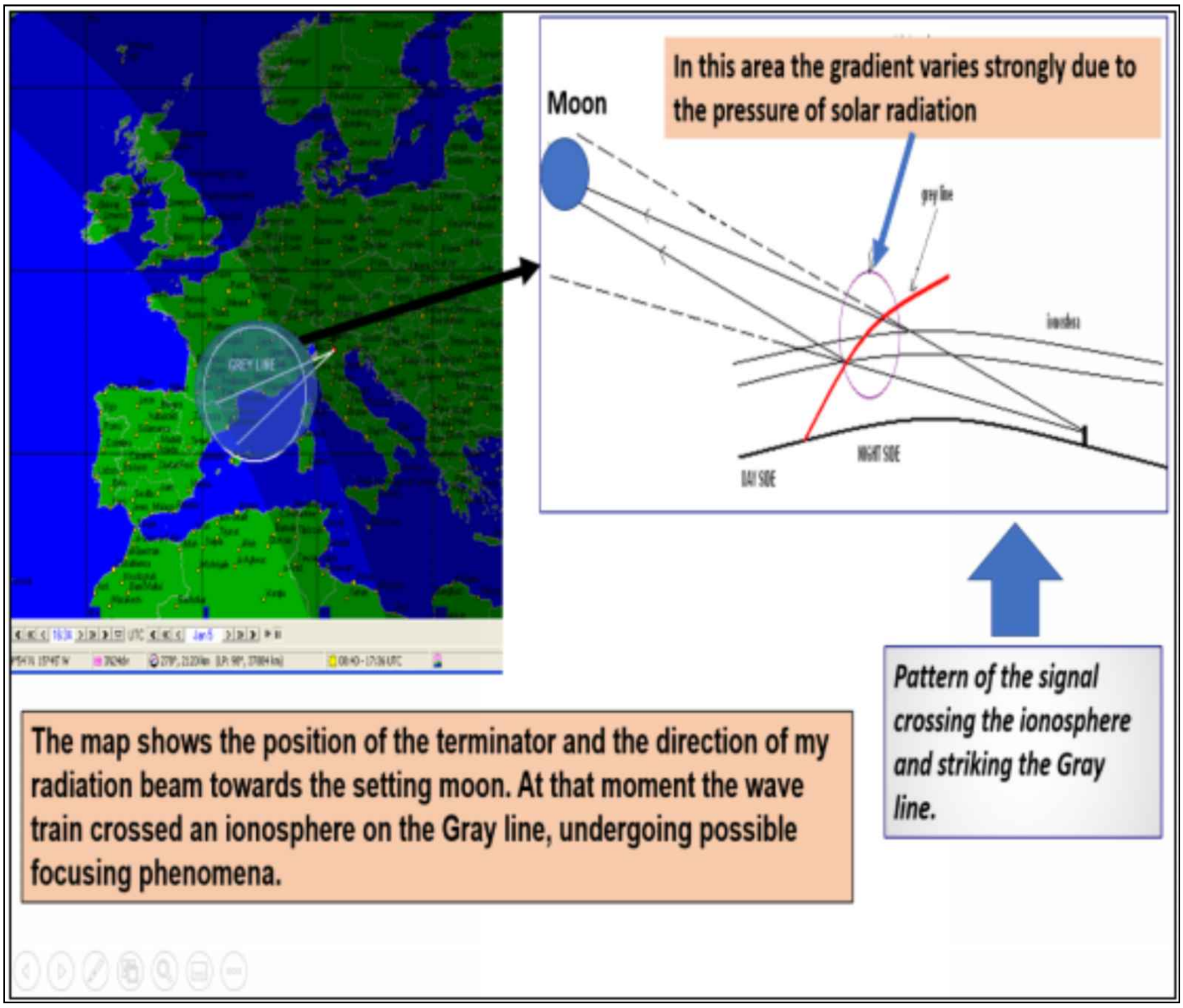


Fig. With a little imagination, I draft what could have happened to focus the signal towards the moon.

The favorable effect of Ground Gain in EME

Another interesting reception is that of the Australian station, VK3KH from Melbourne, which took place on 7 October 2010 at 07:50 UTC. The Australian station transmitted with only a 13 elements single antenna Yagi and low power, only 120 watts. I Received his signal with my 2 x 8 elements Yagi. This is certainly a good example of the advantages you have when the moon is low on the horizon and therefore you can benefit from the Ground Gain.

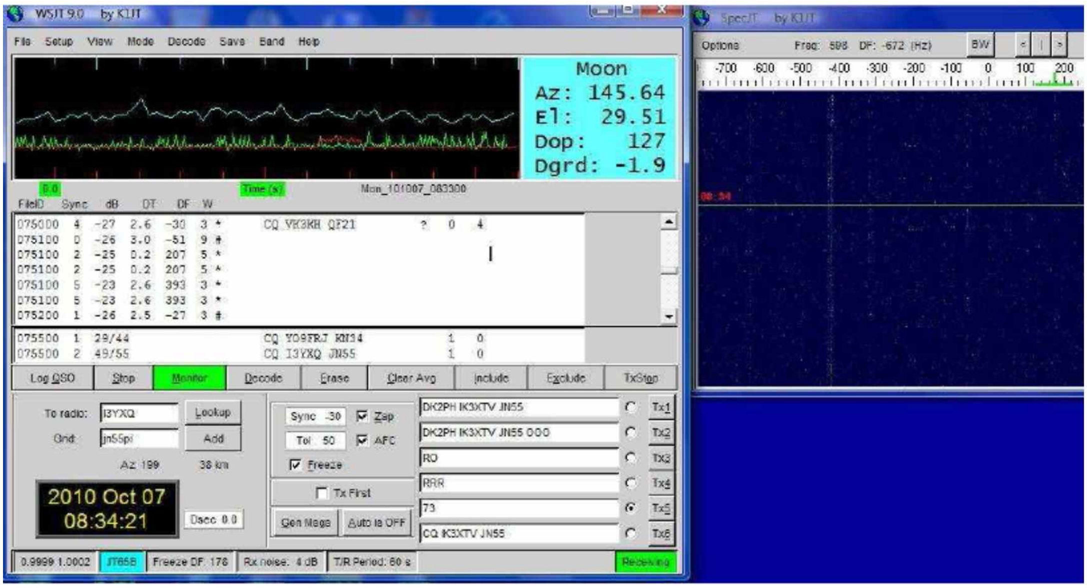


Fig. Screenshot of WSJT with VK3KH EME signal received at 07:50 UTC at -27 dB.

I remember that I was surprised when I saw this signal from Australia appear in the waterfall of my computer. On the EME chat, I had seen that this station was small. Even smaller than mine. At that point I went to investigate why I was able to receive that very faint signal via the moon. I saw that the Australian OM lived in Melbourne, with its antenna pointing towards Port Phillip Bay with the moon setting, at that time at about 2 degrees above the horizon. The ideal situation to have a good ground gain. As demonstrated by the computer simulations, the Ground Gain, when the station is surrounded by a good, decently conductive ground plane, this can give a 6 dB increase, so a single Yagi can reach the performance of 4 Yagi. This gain occurs with the first lobe, depending on the height of the antenna with respect to the ground and occurs at about 2-4 degrees of elevation. VK3KH, overlooks the bay and its ground gain is given by the sea. This is an even better situation to have a good GG. Salt water is an excellent conductor and therefore, if the surface is calm, it is also an excellent mirror for the GG which can reach up to 6 dB. A friend of mine, with a lot of experience in EME communications, and equipped with an excellent station told me that he had listened to many EME DX expeditions on various islands in the Pacific and noticed that their signal increased by at least 6 dB when they operated near the moon set above the sea.
So, the improvements due to the sea are certain. I am not able to establish if the marine GG is sufficient to explain this reception or if there is a further additional factor able to further improve the propagation, such as some focusing effect that I have already spoken: The famous lens effect introduced by possible ionospheric anomalies. Most of the EME community considers Ground Gain to be the only explanation for receiving some very weak signals and are very skeptical of any other hypothesis.

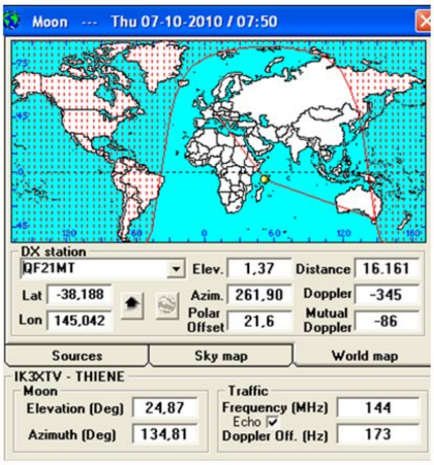
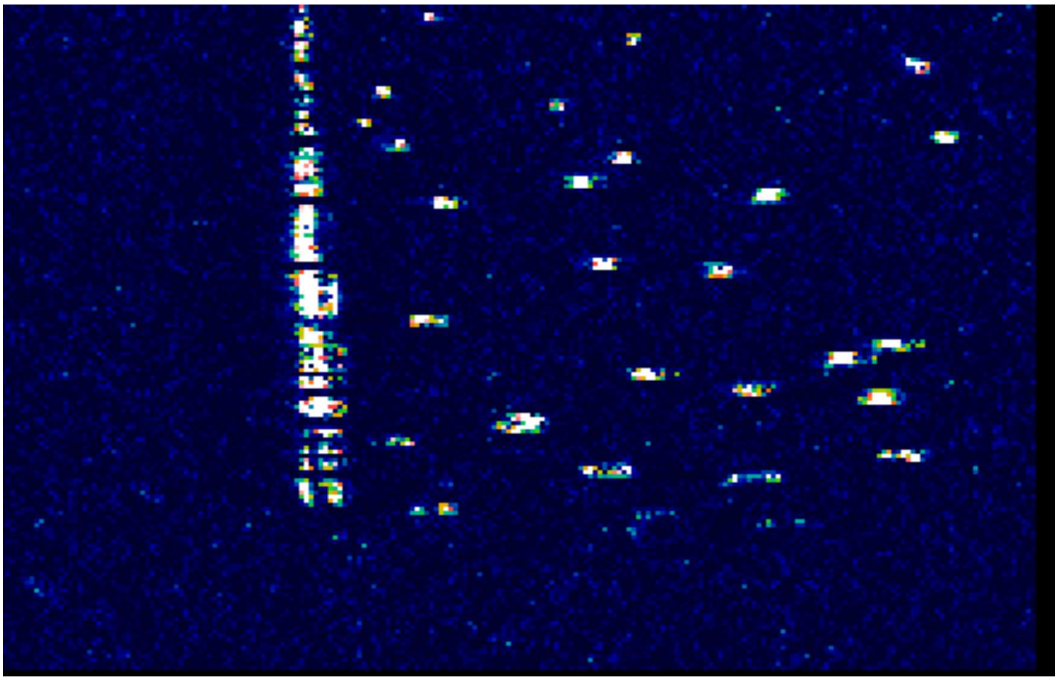


Fig. The location of VK3KH overlooking the Melbourne Bay. At that moment, the moon was at only 1.37 degrees of elevation and was setting on the sea of Melbourne Bay. Even near sunset, it was not yet on the grey Line.
In the image on the right, there are VK3KH's moon data and mine. As you can see, I had the moon at almost 25 degrees elevation, so without any GG. Map created using the DX Atlas software, www.dxatlas.com. Moon calculation image created with EME SYSTEM By F1EHN.

Meteor scatter

It is a radio propagation mode that uses ionized meteors trail as they burn as they enter the atmosphere to establish communication between radio stations up to about 2,200 kilometers away. As the Earth moves along its orbital path, millions of particles known as meteors enter the Earth's atmosphere every day, a small fraction of which has useful properties for communication. When these meteors begin to burn, they create a trail of ionized particles in E layer of the atmosphere that can persist for several seconds. Ionization traces can be very dense and therefore used to reflect radio waves. Frequencies that can be reflected by a particular ion trail are determined by the intensity of ionization created by the meteor, often as a function of the initial particle size, and are generally between 30 MHz and 144 MHz The distance over which communications can be established is determined by the altitude at which ionization is created, the position on the Earth's surface where the meteor is falling, the angle of entry into the atmosphere, and the relative locations of the stations attempting to establish communication. Since these ionization traces exist only for fractions of a second up to a few seconds in duration, they create only short windows of opportunities for communication. For this reason, extremely fast decoding systems are needed.

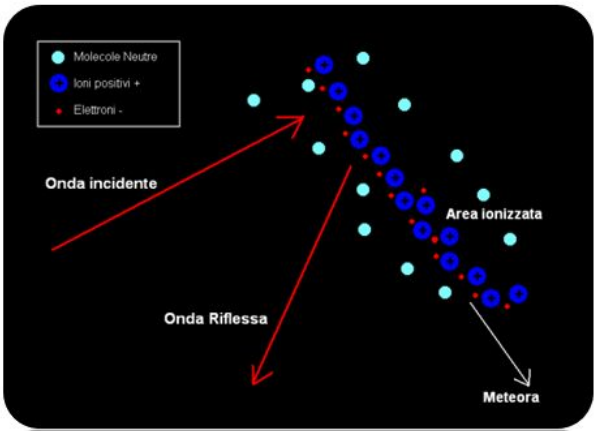


Meteor Scatter in VHF

The reflection of the radio wave

The meteor trail is made up of ionized particles represented by a mixture of positive ions, negative electrons and neutral molecules. When an electromagnetic wave hits the trail, the electric field of the wave produces a displacement of electrons and ions; the displacement of ions is much smaller than that of electrons, because an ion weighs much more than electrons. The intensity of the reflected signal depends on the electronic density and how this varies over time.

They are the free electrons that interact with the radio wave and are therefore responsible for refraction



The Meteor Stream

It is estimated that a few tens of billions of micro-meteorites with a diameter ranging from a few microns (cosmic dust) to a few mm, not counting the larger particles, enter the atmosphere daily at a speed of the order of 100,000 km/hour. Ablation occurs at the height of E layer, where the chances of collision with gas molecules are greater (due to high density).

We have two types of meteor flux:

• Random Meteor Stream
• Meteor Shower (these are periodic swarms such as the Perseids in August)

Dissipation processes of an ionized trail

When a meteor enters the Earth's atmosphere, friction overheats, resulting in the formation of a highly ionized trail. Then there is a dissipation where various processes contribute:

1. Electronic diffusion in the surrounding environment and along the path
2. Electronic recombination with ions
3. Association of electrons with air molecules

The ablation process takes place at about 100 km of altitude, where the molecular density becomes high. The maximum peak of meteor flux occurs around 6:00 AM local time. Between midnight and dawn, the earth moves directly impacting the meteor shower. In this range meteors reach the maximum entry speed. It should be borne in hand that night meteoric skis have a longer duration than daytime, this is because the electron density is at its lowest at night.

The best time

The best time is the morning before sunrise as two favorable effects are added together: the greater number of meteors and the slightest ionization of the Ionosphere. As can be seen from the Total Electron content (TEC) graph, the electron content in the Ionosphere is at its lowest overnight, with a further minimal peak just before sunrise. Thus, given the low density of night ions, the recombination times are longer, with the result that free electrons are more important in the early morning. (Free electrons are the responsibilities reflection of the incident radio wave).

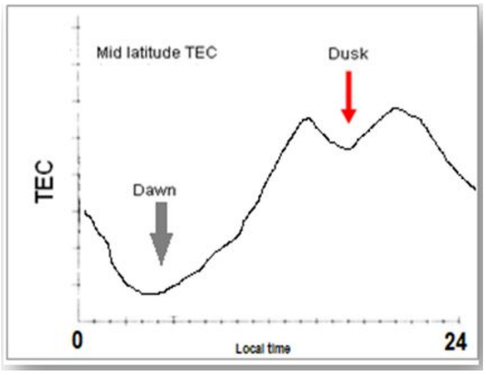


Fig. Example of a daily TEC curve. Observe the pre sunrise dip, because there is all days.

Changes in the meteor flux

The flux of meteorites is not constant but has significant daily and seasonal variations. The maximum peak occurs in the morning before sunrise, then gradually decreases. There is also a significant seasonal variation with an important increase during the summer months. (The meteor flux is about 6 times higher and this is due to the 23° inclination of the Earth's axis of rotation).

The reflection of the radio wave

The meteor shower consists of ionized particles represented by a mixture of positive ions, negative electrons, and neutral molecules. When an electromagnetic wave affects the wake, the electric field of the wave produces a displacement of electrons and ions; the displacement of ions is much smaller than that of electrons, because an ion weighs much more than electrons. The intensity of the reflected signal depends on the electronic density and how it varies over time. It is the free electrons that interact with the radio wave and therefore those responsible for refraction.

Reflection properties of ionized traces

Meteors can have a mass ranging from 10^-5 to 10^-1 grams (with a diameter of 0.2 up to 2

mm) produce suitable for communications. These skis are located at an average altitude of 100 km, with a typical length of 15 km, although in some cases meteoric traces up to 50 km long have been recorded. The initial radius of the wake is typically in the order of m 0.5-4, and expands by diffusion, usually dissipation occurs in a few seconds, or tenths of a second. Initial radius of the wake that at the time of its formation is about ten centimeters. Then it gradually expands by diffusion.

Under dense and Over dense trail

How a meteor reflects radio waves depends on the density of free electrons in the ionized wake. Here we will talk about two boundary cases:

1-Very low electron density (under dense trail) characterized on a practical level by the so-called "pings"
2-Very high electronic densities (over dense trail) (Burst)

The electron density of a meteor shower is high enough to reflect the RF. The intensity of reflection decreases as the frequency increases. In the early morning, electrons and ions recombine slowly, reducing ionization and thus the reflection capacity of the track. The duration of the track's reflection capacity also decreases rapidly as the frequency increases. With FSK441 mode, the duration of a message is 100 ms, so in 144 MHz even very short pings are enough for a QSO.

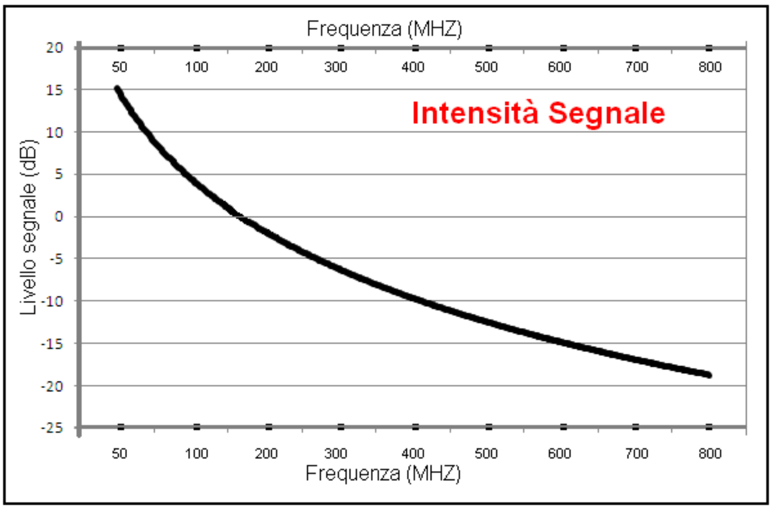


Fig. Relative signal strength based on frequency.

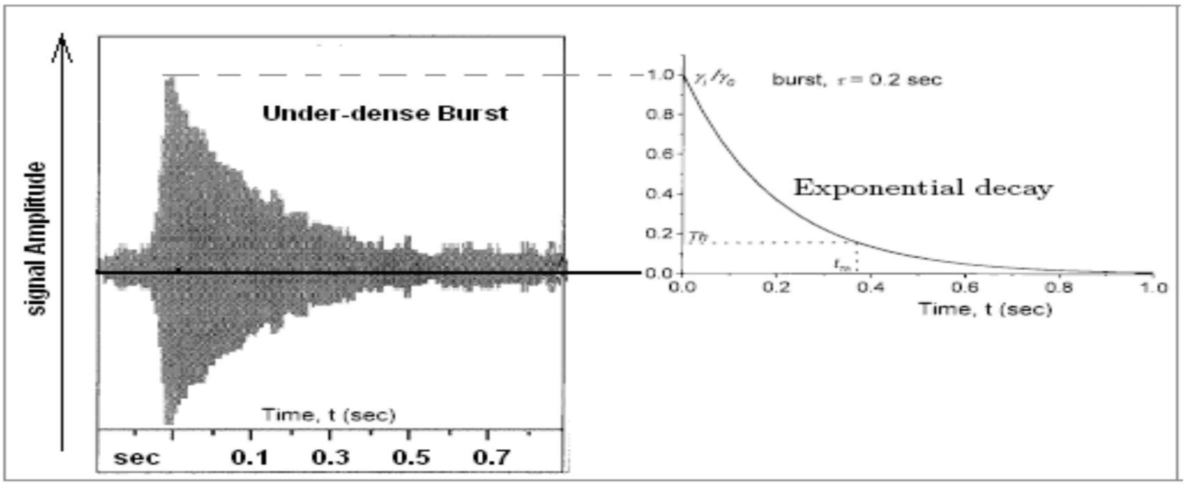
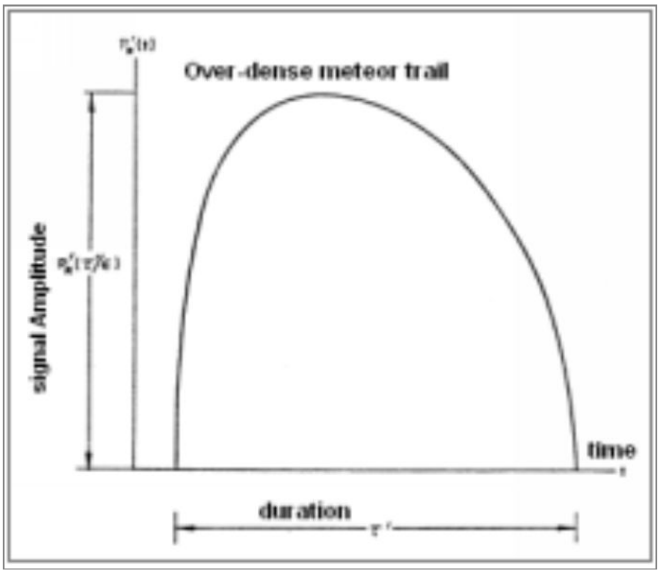


Fig. The signal spectrum and the exponential amplitude decay.



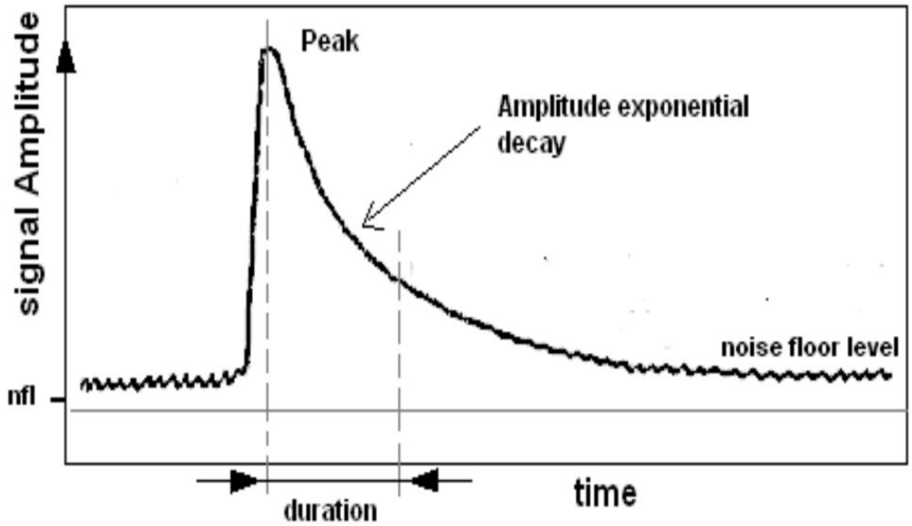


Fig. Types of radio echo from a meteor trail. Shape is quite different for either under dense (diagram left) and over dense trails, (diagram right).

Doppler frequency: the effect of ionospheric winds

There are two types of velocity in a meteor event. The speed of the same meteor, (a few dozen
Km/sec, and the speed of the ionized track which is equal to the speed of the winds at altitude. These strong winds (up to 100 m/sec) deform and move the ionized track (plasma) with the consequence that

the reflex signal is afflicted by dopplers. The plasma is diverted by the ionospheric winds present at these altitudes. There is movement of the wake by speed of the winds at high altitude, and therefore a mini-doppler that widens the frequency received. We therefore have a mini-doppler to widen the wake, resulting in widening of the spectrum and a doppler to move the wake due to neutral winds.
In addition to short-lived and well understood under dense / overdense meteors, there are occasional events of long-lasting meteoric echoes with durations ranging from a few seconds to many minutes. Such long-lasting meteoric events are quite exceptional and a mystery. Every now and then it happens to receive long echoes with durations ranging from a few seconds to a few minutes, detected in VHF both at mid-latitudes and at high and low latitudes. These echoes have broad doppler spectra like those obtained when the plasma of the E region becomes highly unstable, such as in the presence of sporadic E. But why do these trails last so long? Unfortunately, I have a simple answer as these long-lasting meteor echoes remain a mystery. These trails are characterized by the bifurcation of the doppler spectrum. The doppler could be caused by the fragmentation of the meteor trail by the vertical wind shear (the same we have seen for the sporadic E). A similar thing could happen, namely a rapid scattering of the ions swept by the ionospheric wind.

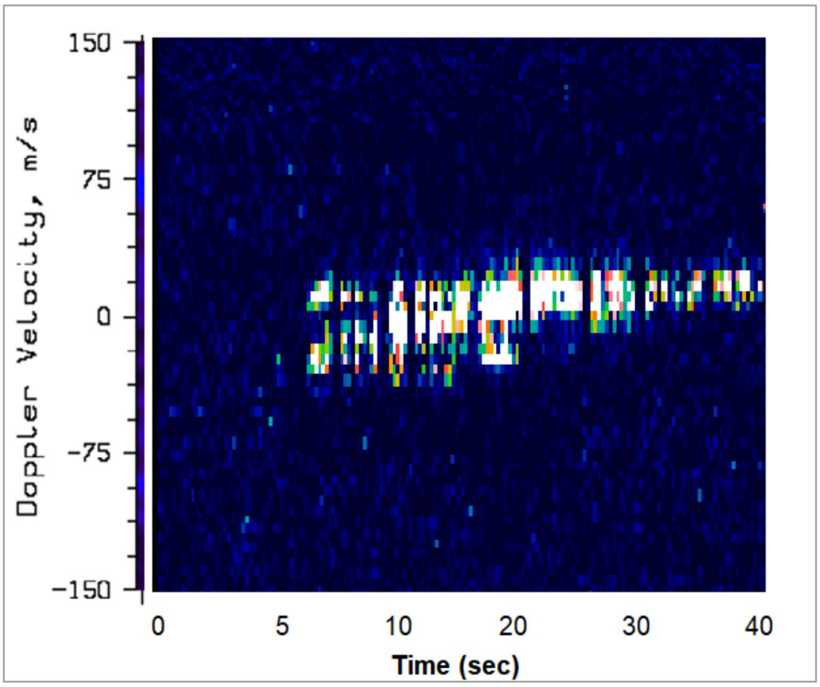

150
75
0
-75
-150
Doppler Velocity, m/s
0
5
10
20
30
40
Time (sec)

Fig. Example of long reflection in VHF, characterized by the bifurcation of the doppler spectrum. (Analysis of the echo received by F6APE in 144 MHz).

Persistent tracks in VHF 144 MHz

There are rare events of long-lasting echoes ranging from a few seconds to a few minutes. They have been observed in HF (15 MHz) and VHF (50 MHz). But they are also possible in VHF (144 MHz). This type of reflections has a distinct spectral Doppler form characterized by a fork. VHF (144 MHz) recorded tracks lasting up to 160 seconds.

Connection with the sporadic E?

But why do these reflections last so long? Unfortunately, the answer is not easy. Long-term reflections have been a mystery for many years. Since the doppler structures highlighted can be caused by the fragmentation of the wake from the vertical Wind Shear. It is hypothesized that ionization could be maintained by the convergence of free electrons, as in the case of sporadic E formations under the action of inverse zonal winds which, with the help of the Lorentz force, converge electrons towards the ionized zone.

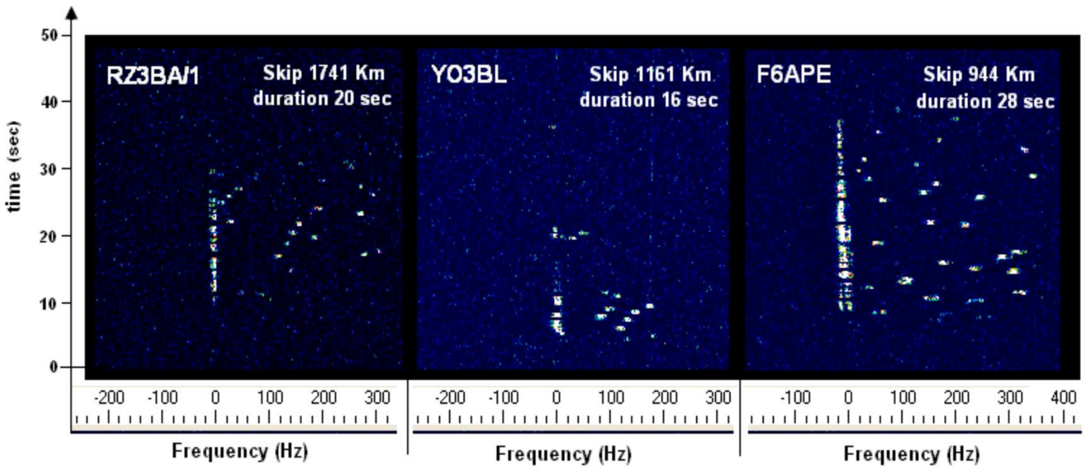


Fig. Examples of long reflections in VHF (144 MHz). Experiments done with JT65B.

The most used digital ways: WSJT

	JT6M: used for meteor scatter communication in 50 and 70 MHZ Suitable for longer and weaker reflections. It can work with signals that are up to 13 dB weaker than those required for FSK441.
	FSK441: Used for meteor scatter communication in 144 MHz and 432 MHz more suitable for short but strong reflections. FSK441 can decode pings up to 100 ms in duration.

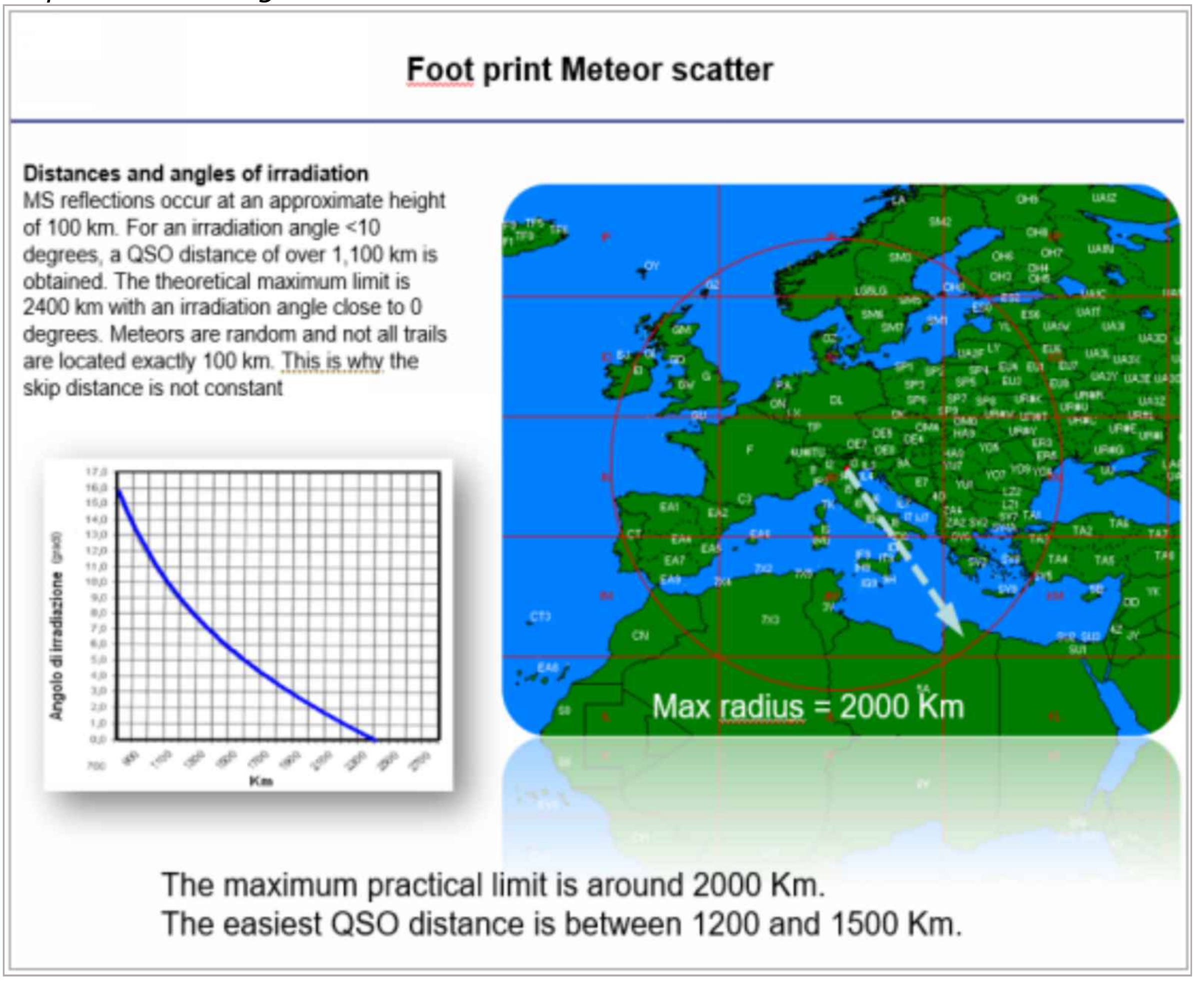
Irradiation distances and angles

MS reflections take place at an approximate height of 100 km. For an irradiation angle < 10 degrees, a QSO distance of more than 1,100 km is obtained. The theoretical maximum limit is 2400 km with an irradiation angle close to 0 degrees. Meteors are random and not all skis are exactly 100 km away. That is why the skip distance is not constant. The maximum practical limit is around 2000 km. The easiest QSO distance is between 1200 and 1500 km.

Tropospheric extension of meteor scatter

In exceptional cases, an extension of the connection distance is possible thanks to the contribution of tropospheric propagation. Experiments have been conducted, for example between Australia and New Zealand with QSO MS + Tropo ducting up to 2900 km, in the band of 2 meters with FSK441 (Source “Dubus” 04/12). We will see something more detailed in the next pages.

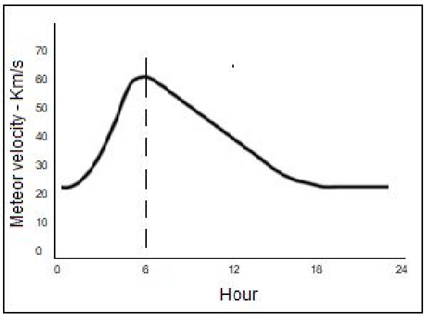
Map created using the DX Atlas software, www.dxatlas.com.



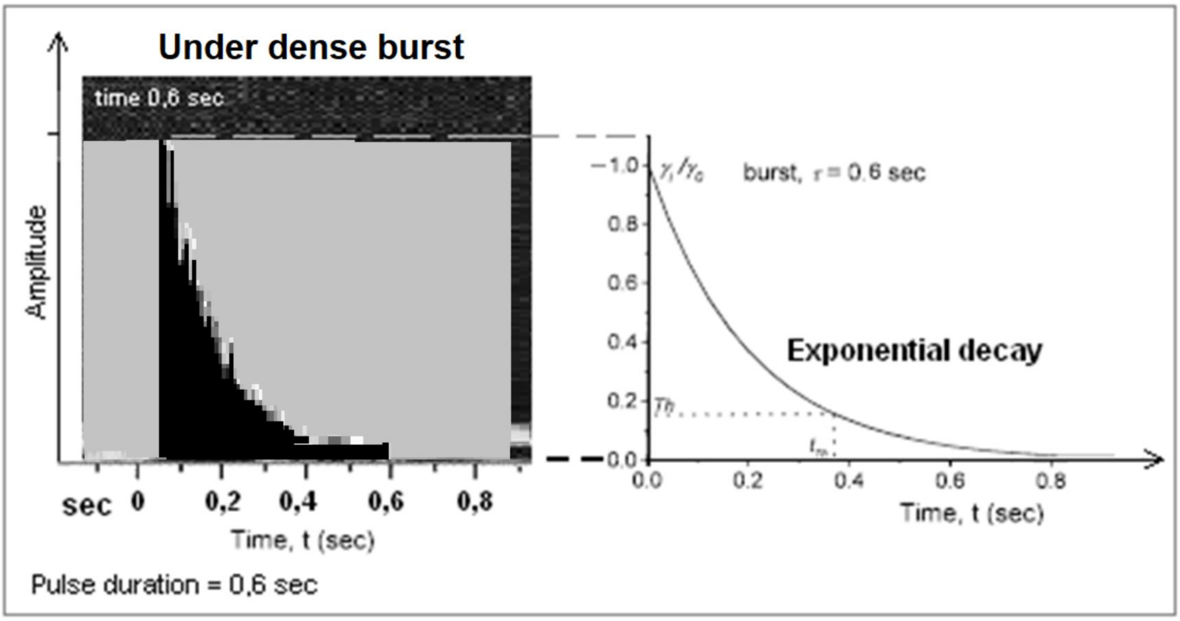
Speed and duration of ionized trails

Due to the gravitational attraction of the earth, the minimum speed with which a meteorite enters the earth's atmosphere is about 12 km/s, while the maximum speed depends on the origin of the body and the direction of its motion. It therefore turns out to be about 72 Km/s, as the sum of the speed of the earth around the sun (29.7 km/s) and the escape speed of a particle from the solar system near the earth (42.1 km/s).

As a result of the earth's revolution, the peak speed is reached at dawn



Duration of the trails
Night meteor trails have a longer duration than daytime ones, this is because the electron density is at its lowest during the night.



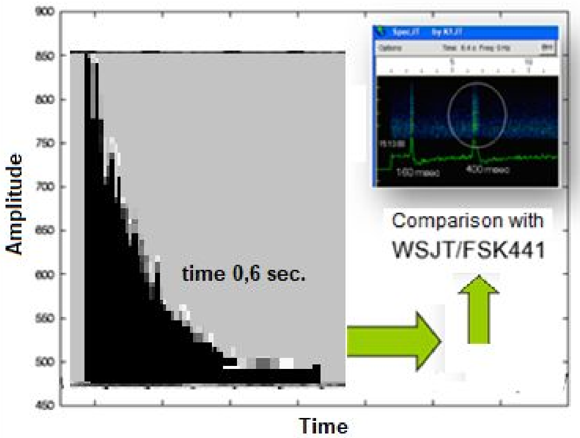
Overdense and underdense trails

The way a meteor reflects radio waves depends essentially on the density of free electrons in the ionized trail. Here we will talk about two borderline cases:

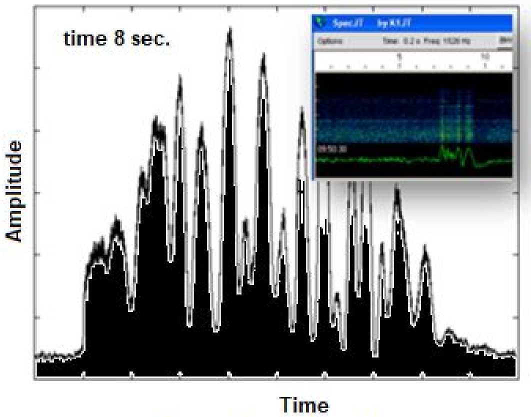
1- Very low electron density (underdense trail)
2- Very high electron density (overdense trail)

Most of the trails are underdense

Meteoric trails are classified according to their electron density:
Underdense (n < 2*10^14 m-1)
Overdense (n >= 2*10^14 m-1)

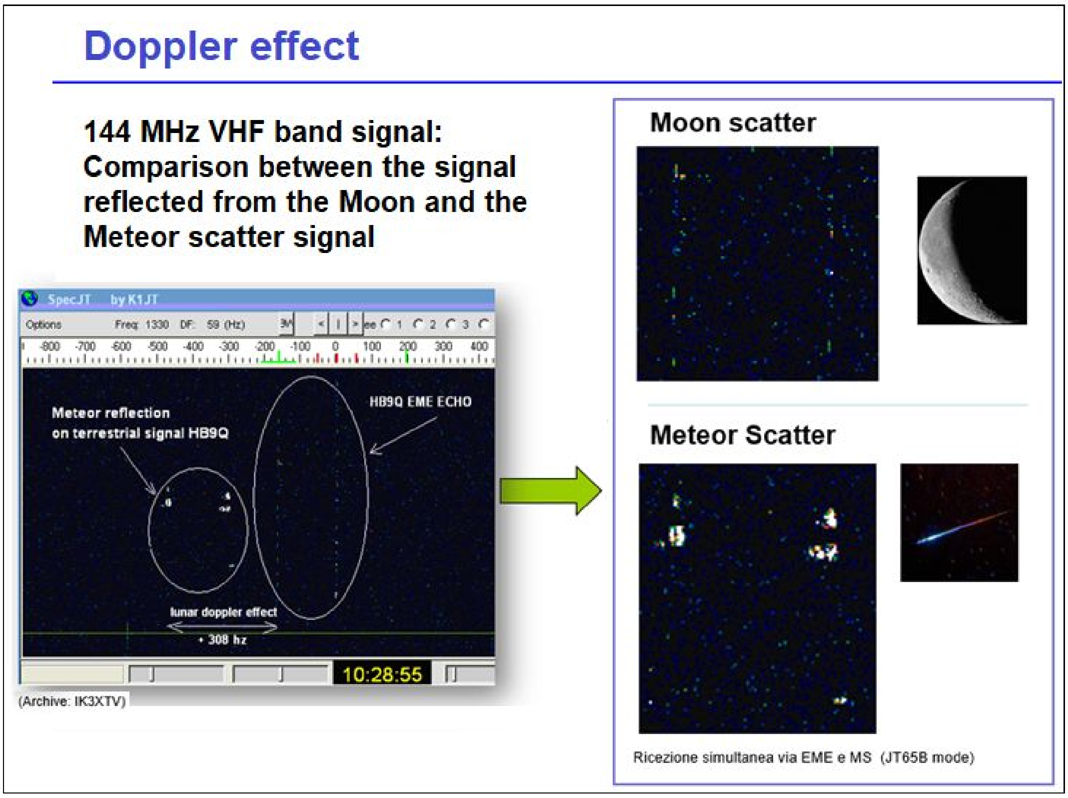


Underdense trail



Overdense trail

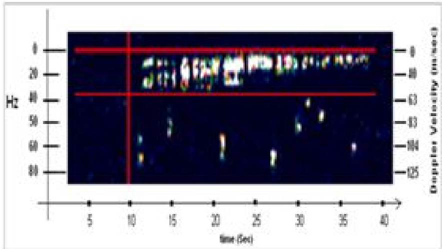
*Fig. Example of the signal spectrum and the exponential decay of the amplitude. There are two basic types of meteoric echoes, depending on whether the linear concentration of electrons in the reflective trace is greater or less than a certain limit value. When the electron density of the trace is less than about 2.4 * 1014 el / m, the reflection gives rise to a hypodense echo, if the electron density is greater than this value, a hyperdense echo is formed. However, the duration of the echoes is very varied and strongly depends on the wavelength used and the height of the reflection point.*



Doppler frequency: The effect of ionospheric winds

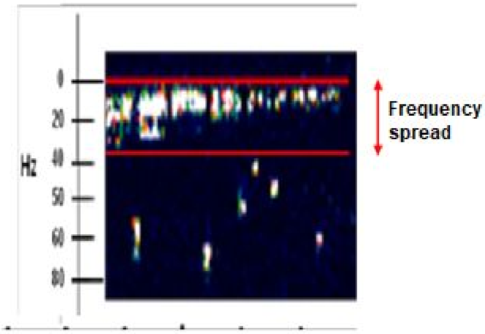
There are two types of velocity in a meteor event. The velocity of the meteor itself, and the velocity of the ionized trail, which is equal to the velocity of the winds at altitude. These strong ionospheric winds (up to 100 m / s) deform and displace the ionized trail (plasma) with the consequence that the reflected signal is subject to doppler.

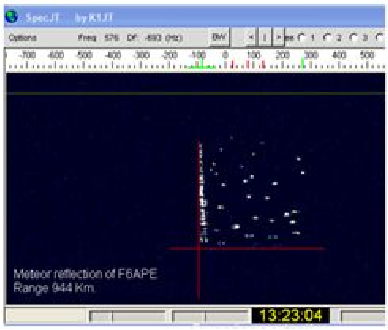
The plasma is deflected by the ionospheric winds present at these altitudes



There is movement of the trail caused by the speed of the winds and therefore a mini doppler which broadens the received frequency

There is not only trail widening mini-Doppler, but also a trail displacement Doppler due to winds





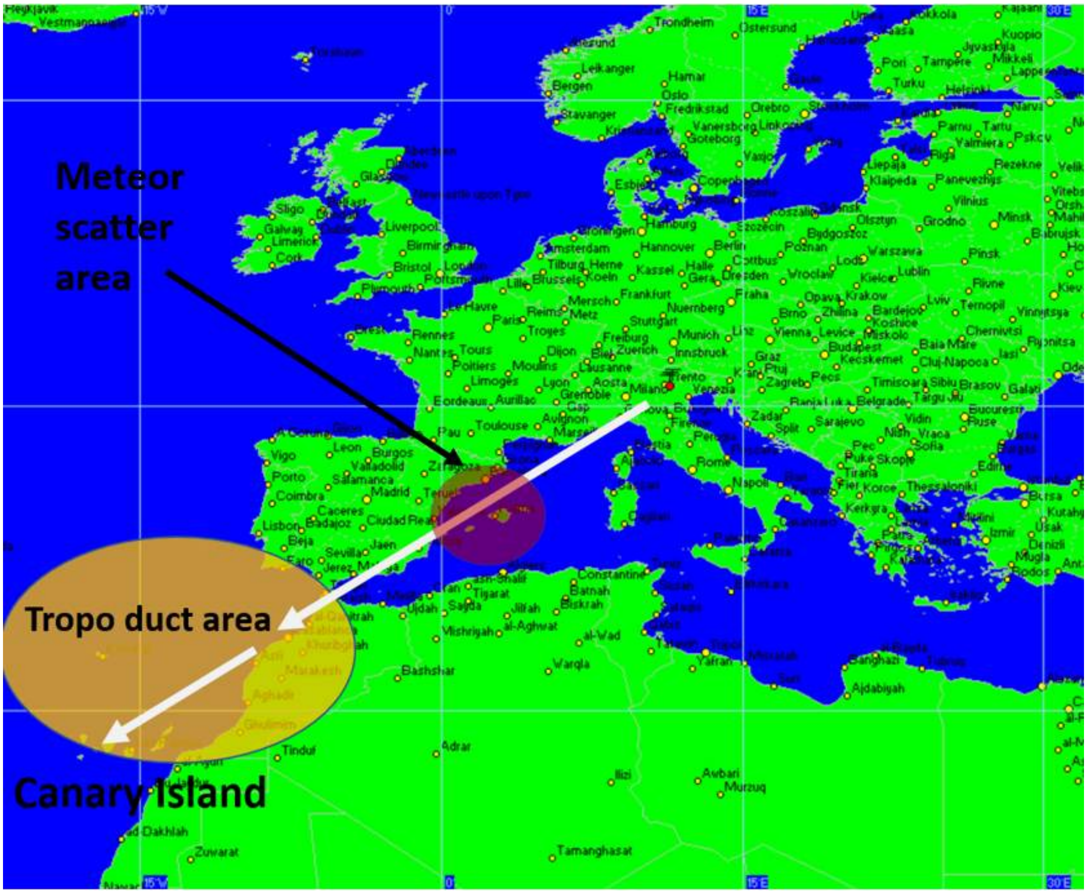
Tropospheric extension of Meteor scatter

Introduction

During the ARI - VHF 2013 Conference, I had the opportunity to discuss the potential tropospheric extension of Meteor scatter, which allows for extending the connection distance to over 3000 Km. Remarkable QSOs with record-breaking achievements were made during the swarm of August Perseids, confirming these capabilities. On August 12, a new MS world record was achieved between S50C in Slovenia (JN76JG) and EA8TJ (IL18RJ) in the Canary Islands, with a QRB of 3377 Km. The following day, August 13, I2FAK completed another QSO (Italian Record and 4th World Record) with EA8TJ at 2929 Km. Now, let us take a closer look at the factors that allowed these exceptional results.

Meteor Scatter with tropospheric extension

Since meteor reflections occur at an approximate height of 100 km, with an irradiation angle close to 0 degrees, the theoretical maximum limit is about 2400 km. Therefore, to achieve distances of more than 3000 km, tropospheric ducts were exploited over the sea, extending the path by an additional 500 kilometers. The primary and longest stretch was facilitated by the meteoric reflections of the Perseids, reaching beyond the area of the Strait of Gibraltar. Subsequently, a tropospheric duct over the Ocean was utilized, leading to the Canary Islands. As evident from the tropo prediction card in the Figure on the next page, which was valid at 18 UTC on August 13, particularly favorable conditions were observed above the potentially involved area (indicated by the red spot).



Meteor scatter area
Tropo duct area
Canary Island

Fig. Meteor scatter + tropo extension mechanism. Very often, there are excellent tropospheric propagation conditions, including the formation of tropo ducts, especially in the summer months in the sea area beyond the Strait of Gibraltar, on the Atlantic Ocean, off the Moroccan coastline. The signal entered this tropospheric area after an initial skip, supported by the first meteor scatter reflection, in the approximate area over the Balearics Islands. It is essential to consider that in the Atlantic area between Spain and the Canary Islands, intense inversion layers exist between 1000 and 2000 meters above sea level, indicating significant discontinuities in air temperature and humidity. These conditions are highly favorable for the formation of tropospheric inversion ducts. Similar weather conditions have allowed exceptional QSOs via tropo between the UK and the Canary Islands, and some record QSOs between England and Cape Verde (M0VRL – D44TD. Tropo Dx Record 4106 Km). In this area, the strong temperature inversions are created by the warm air coming from the Iberian Peninsula to the north and from North Africa, including the Sahara Desert, further south, overlapping with the vast sea surface with relatively cold water, such as the Atlantic Ocean. Such ducts are sometimes formed between Hawaii and California (4000 km) at an altitude of over 1000 meters on the Hawaii side. Map created using the DX Atlas software, www.dxatlas.com.

Tropospheric ducting: a few of theory

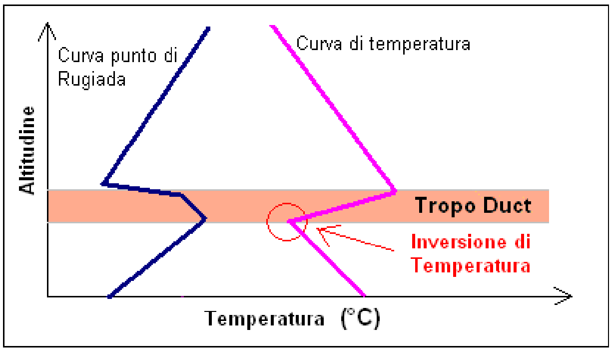
The temperature typically decreases gradually with altitude. However, when there is a layer with increasing temperature at some point, it is called thermal inversion. Over the seas, extensive surfaces can be formed with multiple temperature reversals. The occurrence of a thermal inversion causes the moisture content to decrease at higher altitudes (around 100-2000 meters), leading to discontinuities in both air temperature and moisture content. As a result, significant discontinuities are present in the vertical distribution of atmospheric refraction, which creates channels for radio waves. In other words, there is a sharp variation in the refractive index 'n' due to the differing moisture content in various air layers. Refraction is the deviation experienced by a wave as it travels through a layer where the density decreases towards the top, causing it to undergo progressive curvature and behave as if it were inside a wave guide within the thermal inversion layer. The speed of light in a medium is slightly lower than in vacuum, and it decreases with increasing density of the medium. As a result, the velocity of the wave traveling through the bottom of the inversion layer (the densest part) is lower than that of the wave passing through the top of the layer. This leads to the bending of the trajectory. Certain density variation values correspond to a curvature exactly equal to the Earth's curvature, resulting in the formation of the tropospheric duct. The most favorable weather conditions occur when large masses of cold air collide with warm air, leading to a temperature reversal. This margin between the two air masses can extend over 1000/1500 kilometers along a high-pressure front. Such temperature reversals are most frequently observed over the sea.

$$n = c / v$$

n is the refractive index

c is the speed of an electromagnetic wave in vacuum (about 300,000 km/s),

v is the speed of electromagnetic wave in the medium



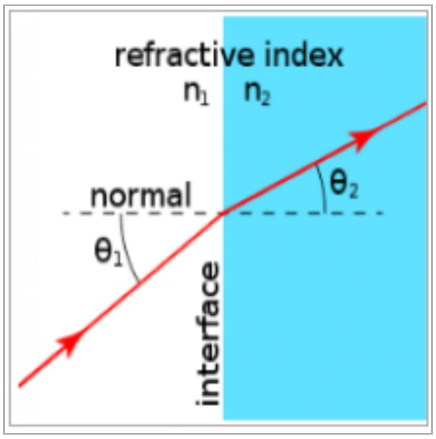


Fig. Outline of the formation of a duct. If we look at a vertical profile of the atmosphere, we can see that there is a sharp increase in temperature (a reversal), associated with a sharp decrease in dew temperature (indicating a decrease in humidity). The duct occurs in the vicinity of this inversion (in the brown shaded area). The refraction of light (and by analogy of an electromagnetic wave) to the interface between two means with different refractive index n2 > n1. Since the velocity in the second half is lower, the refractive angle θ2 is less than the angle of incidence θ1. A radius curvature then occurs. (Image Wikipedia. Public domain).

Characteristics of ducts

In VHF the height of the temperature reversal must take place at an altitude of about 200/300 meters (about 100 meters in UHF) for the formation of a duct. The most favorable weather conditions are faced with high pressure accompanied by cold area. Sea wind accompanied by warm air coming from the mainland the most favorable areas are those above large sea surfaces with rather cold water, traveled by fronts of dry air above.

Long term reflections

Especially the QSO of I2FAK but partly also that of S50C show some persistent traces, with a reflection of more than 20 seconds). In some cases, long-lasting echoes occur ranging from a few seconds to a few minutes. They have been observed in both HF and VHF (144 MHz). Tracks lasting up to 160 seconds were recorded, associated with the most intense meteor showers, as in the case of the August Perseids. These reflections should be caused by the fragmentation of the trail from the vertical Wind Shear. It is therefore hypothesized that ionization could be maintained by the convergence of free electrons by inverse zonal winds that with the help of the Lorentz force converge electrons towards the ionized wake and thus lengthen the recombination times. This is the same principle that undersea the formation of the sporadic E layer.

Considerations

It is helpful to provide some comments on propagation. For efficient entry into the tropospheric duct, the signal must arrive at a very low angle. Thus, a sufficiently long meteor component is necessary, covering a stretch of path of at least 1800 to 2000 km. This seems to be what happened in these exceptional QSOs. Tropospheric ducts of a few thousand kilometers have been identified. Therefore, theoretically, once the signal has connected with the duct, connections over even larger distances would be possible. However, the main challenge lies in the lack of other stations along the extended route. It is worth noting that between the north-west of Spain and the Canary Islands, intense inversion layers are often present between 1000 and 2000 meters above sea level, indicating significant discontinuities in air temperature and humidity. This sharp change in the refractive index plays a crucial role in the propagation process.

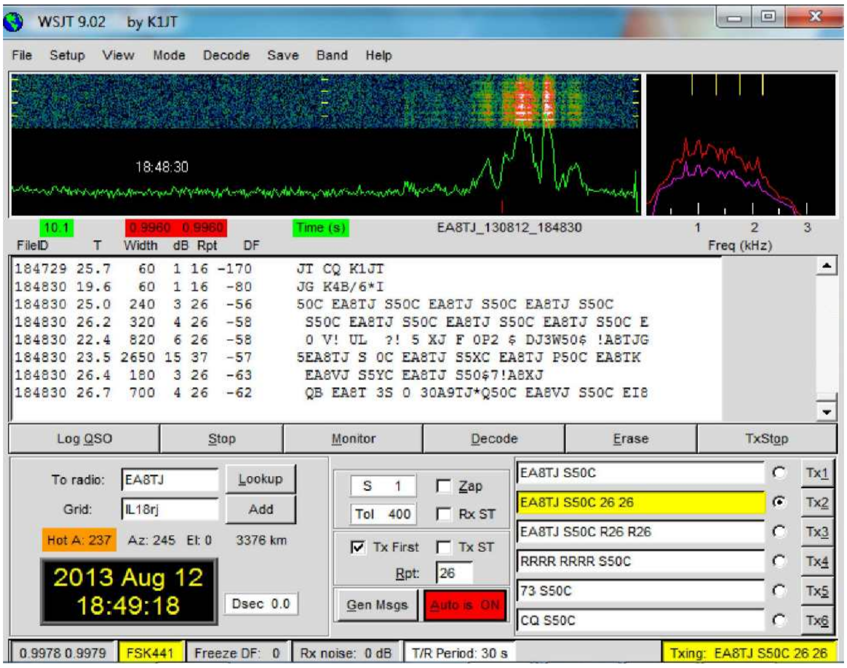


Fig. Some meteor scatter reflections of the QSO between S50C and EA8TJ (working conditions S50C: Ants: 4x18el, 1x20el, 2x15el, 2x15el, 6x5el for 2m RTX: Ft1000mp + Javornik transverter)

(Image Credits: S50C, Radio Club Domzale- Slovenia).

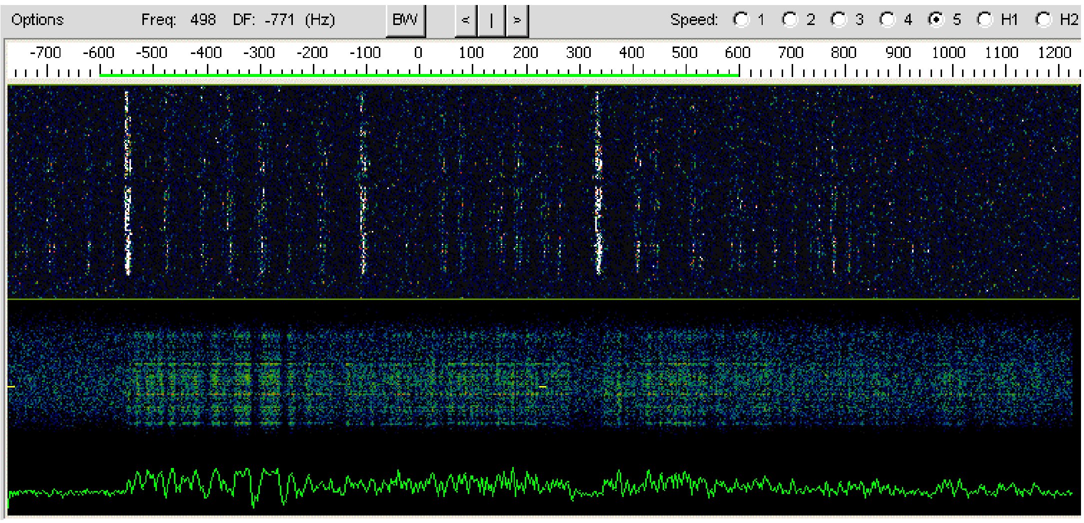


Fig. Screen shot of the exceptional reflection of over 20 seconds of one of the signals received by Franco, I2FAK during the QSO with EA8TJ. (I2FAK Working Conditions: 2 x 19 Log Loop Yagi)

(Image Credits: Franco Giorgi, I2FAK).

EME, Meteor scatter or super tropo? Signal from Russia in 144 MHz

The effects of propagation on the 144 MHz band can sometimes be surprising. I would like to tell this experience about the 144 MHz on May 7, 2010. I was trying to connect via moon a Russian station RZ3BA/1 pointing my two Yagi antennas towards the moon that at that hour was setting behind the Mountains of the Carega Group that rises at least 2400 meters. At that time RZ1BA/1 was engagements in EME QSO with an American station, AD4TJ. My surprise was great when, in addition to the RZ3BA / 1 signal bouncing back from the moon, I also receive at the same time the same signal that arrives on the back of my antennas, strong and via tropospheric path or ionospheric path, or from who knows what other reflection (of meteoric origin?). The Russian station was located at 1740 km. My 2 Yagi antennas were pointing towards the moon, which was setting in the west, in the opposite direction from RZ3BA. Where does this terrestrial signal from Russia come from? Hard to say, I can only make a few assumptions:

- Reflection from the satellite passing in front of my horizon that reflected the RZ3BA signal.
- Strong meteoric reflection of RZ3BA signal.
- RZ3BA super tropo favored by RZ3BA ground gain radiating with very low elevation having the moon at a few degrees of elevation.
- Reflection from some sporadic E clouds.

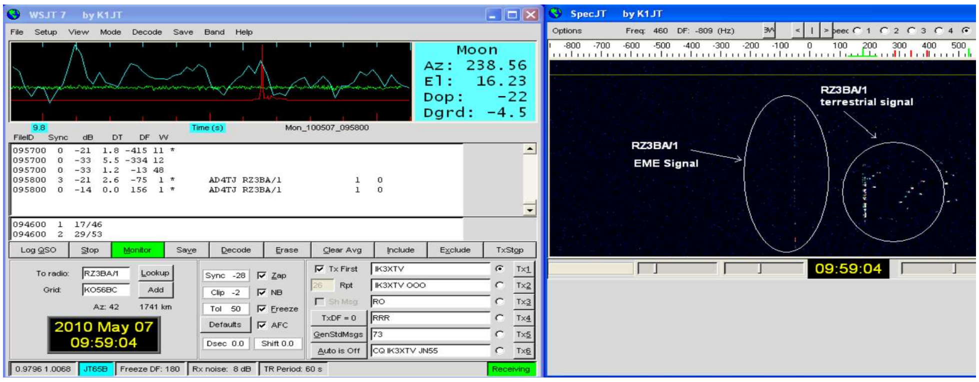


Fig. This is the JT65B software panel. On the left you can see the signal string received at 09:58 UTC, by RZ3BA/1 calling AD4TJ with a dB. level of -21 and a DT (delay time) of 2.6 seconds, the time that the signal takes to make the earth-moon-earth path. The string below, is the same signal received at 09.58 UTC at a level of -14 dB and a DT of 0.0 seconds, with a *doppler of 231 Hz which means that the signal followed a short path, of type "Terrestrial". On the right side of the image, you can see the two signals graphically in the spectrum. The frequency difference between the two signals, the moon and the t-signals,* is the *Doppler due to the movement of the moon with respect to the earth and turns out to be -231 Hz. In the spectrum panel on the right, in fact, the horizontal axis represents the frequency while the vertical axis represents the time.*

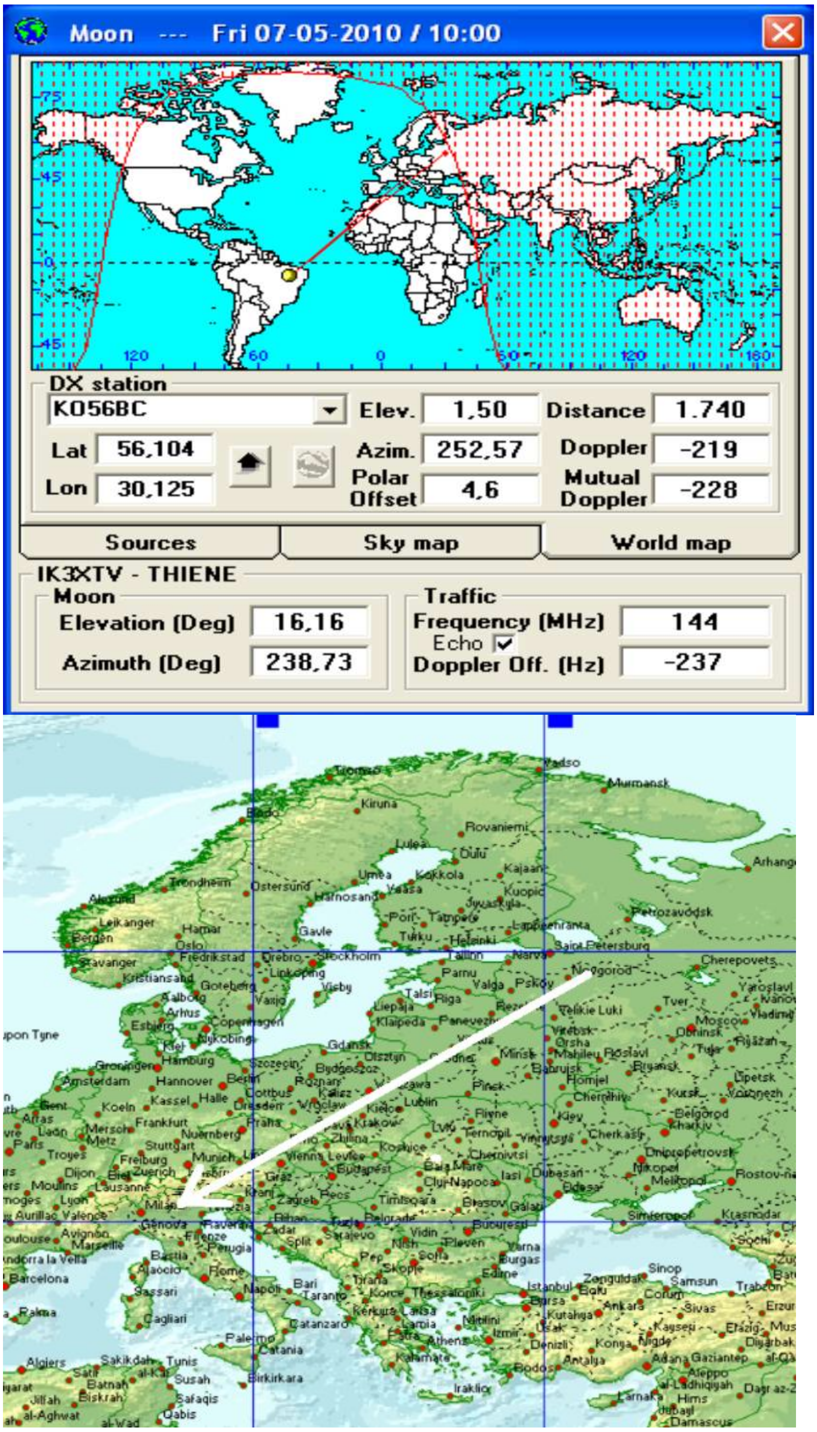


Fig. On the left the map with the geographical location of the Russian station RZ3BA/1 and on the right the astronomical data relating to the position of the moon with respect to my station and the Russian station.

Analyzing the terrestrial signal very closely, we note that it does not present any frequency drift. Usually reflections on moving objects, such as artifice satellites, aircraft, or even meteorites, have a frequency drift (frequency drift) of a few Hz, due to the doppler effect introduced by the moving object. This leads me to think of a reflection on something firm, as could be a sporadic E formation.
The signal, however, seems to show a slight drift from enlargement (frequency spread). The track appears slightly wider than the signal reflected from the lunar surface. All information that makes me think of a meteor reflection. The figure below highlights the same phenomenon with another EME station, HB9Q from Switzerland. Here, too, you can see some meteor reflections.

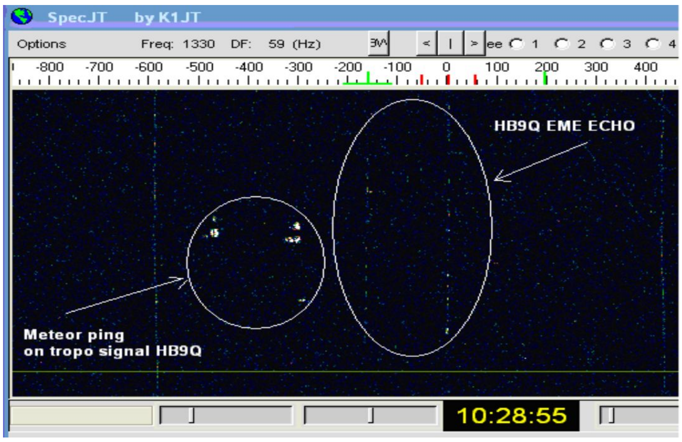


Fig. This image shows meteoric reflections on the HB9Q signal looking for EME connections, you can also see the moon echo moved about 300 Hz higher for the doppler effect. Frequency 144 MHZ. (Ik3xtv Archive).

A tribute to the pioneers of ham radio

In the fascinating 1920s, an era when radio amateurs were a rare and select group of enthusiasts, concentrated in the United States and Europe, a common dream animated many of them: to establish connections across the ocean. This endeavor, comparable to a sailor's challenge in rounding Cape Horn and meant more than just a mere dream for them. In those pioneering days, the United States and Europe started picking up faint signals from each other's radio amateurs, a clue that sparked hope for direct communication between the two shores of the Atlantic Ocean. Nowadays, it is something easy and ordinary, but back then, it was impossible, something no one had ever done, and it seemed like an insurmountable challenge. It was on the night of November 27, 1923, an ordinary Tuesday, that the impossible became a reality. Fred Schnell, using the call sign 1MO, and John Reinartz, with the call sign 1XAM, were in Hartford, Connecticut. Incredibly, they managed to establish radio contact with a European amateur radio operator: Leon Deloy, a young French radio enthusiast known by the call sign 8AB, residing in Nice, in the south of France, approximately 6300 kilometers away. This historic event marked the first transatlantic connection in the history of Radiantism. Even before the outbreak of the First World War, Léon Deloy had developed a deep interest in radio, devoting himself to receiving broadcasts in shortwave. This passion led him to become the first French amateur radio operator to obtain authorization for transmissions. Prior to achieving this incredible feat, Leon Deloy embarked on a journey to the United States in early 1923. He boarded

one of those great transatlantic liners of the time to cross the Atlantic Ocean. His destination was Connecticut, where the headquarters of ARRL, the American Radio Relay League, was located, and where he had plans to meet his friend Fred Schnell. During his stay in Hartford, the capital of Connecticut., Deloy had the privilege of meeting a young engineer of German origin named John Reinartz, whose skill in building receivers and transmitters proved crucial for their audacious project. They decided to join forces and construct a transmitting station based on Reinartz's ingenious design, with the goal of attempting a bilateral connection between the two sides of the Atlantic. I can imagine them seated at a table in a restaurant in New England, discussing, fantasizing, and dreaming about their shared passion for radiotelegraphy. Deloy returned to France, carrying with him all the knowledge acquired from Reinartz, and began putting it into practice. He built a shortwave transmitter operating at a frequency of 2.7 MHz, a frequency considered high for that time, but it was a bold choice that turned out to be crucial for the success of their endeavour. Radio amateurs were not allowed to operate below that frequency, as it was reserved for major broadcasting stations. The power used by Deloy and Schnell amounted to approximately 200 watts, a modest figure compared to the powerful transmissions of commercial stations. Finally, on the night of November 27, 1923, everything was ready for the extraordinary event. Deloy had completed his station in Nice, stretching a long wire between two large trees in his garden, which served as an antenna. Through a telegraph, he communicated to the ARRL headquarters that he was ready to transmit. On the other side of the ocean, in Hartford, Connecticut, Schnell tuned his simple receiver to Deloy's frequency and started listening. Hours of silence and atmospheric disruptions passed, but Fred did not give up. With determination, he continued to wear his headphones and listen carefully to the whisper emanating from his receiver, as if he sensed that sooner or later something

significant was about to happen. Then, suddenly, like magic, the first Morse code signals made their way into Schnell's headphones. They were the signals sent by Deloy in Nice, on the Mediterranean coast, at an incredible distance of over 6,000 kilometers. Fred's excitement and joy were indescribable, and he immediately transmitted his confirmation message, which Leon Deloy listened to with the same excitement. Thus, the first transatlantic connection between radio amateurs was achieved. The two friends exchanged messages of congratulations, and Leon said to Fred, "This is a great day!" Even Reinartz, the brilliant engineer, managed to connect with the French station an hour and a half after the first connection with Schnell. It was the beginning of modern radiotelegraphy, as the path had been opened, and in the following months, other daring experimenters managed to communicate via radio across the Atlantic, following the same approaches as the three pioneers. The technological evolution of the subsequent years has led to radio equipment that resembles computers more than traditional radios. Today, we are accustomed to operating with sophisticated transceivers that leverage the most advanced technologies. Frequency reading occurs through highly precise digital displays, and signals can even be visualized on screens with exceptional accuracy. But in 1923, at the dawn of Radiotelegraphy, things were different. At the beginning of the 20th century, commercial communications occurred using long waves, and experimenting radio amateurs were confined to a portion of the spectrum considered useless for long-distance communication. They operated on frequencies with wavelengths shorter than 200 meters, as they had been relegated to that remote corner of the spectrum to avoid creating interferences and disturbances. Nevertheless, radio amateurs bravely challenged these limitations and focused on experimenting with higher frequencies. Operating on higher frequencies presented a series of problems that fascinated and challenged those

enthusiasts. The higher frequencies they used were beyond the limits, and these passionate individuals found themselves having to deal with the constraints of rudimentary electronic components of the era. Variable capacitors, insulators, and resistors were still in the developmental stages and were far from efficient. One of the main obstacles was the frequency stability of their simple apparatus. Transmission and reception devices were still precarious and subject to unwanted frequency variations, making it difficult to maintain stable and reliable communication. They had to face continuous challenges. However, radio amateurs did not give up in the face of these difficulties; instead, they plunged headlong to confront and overcome them, focusing primarily on receivers and utilizing the new electronic valves, which promised superior performance. They had understood that the receivers were the key to everything. This innovation opened new horizons in the field of amateur radio communication. By experimenting and adapting circuits, radio amateurs achieved remarkable results operating on these unused frequencies, considered useless by the science of the time. Three amateurs, operating with limited means and homemade equipment, accomplished a feat that astonished the major international broadcasters and commercial stations. Despite their immense resources, antennas, and high power, these large stations had not been able to achieve the same results as the radio amateurs. They wondered in amazement how it was possible for a group of poor amateurs, with limited means and power, to be heard at such remote distances and achieve results that were impossible for them. Fred Schnell, to tune in to Leon Deloy's frequency, used a homemade receiver with salvaged materials. This showed that the passion and creativity of radio amateurs were the fundamental ingredients for their success. The use of short waves, unconventional for that time, gave radio amateurs a significant advantage over large commercial

broadcasters. But what distinguished radio amateurs and what made the difference, was the dream that guided them. Radio amateurs had to fight to preserve even a tiny space on the shortwaves, which until then had been deemed unusable and abandoned. However, following their successes, those waves that had seemed insignificant just a short while before became a subject of contention among nations, and major international broadcasters quickly seized upon these new frequencies. These men applied the first scientific principle: questioning acquired knowledge. They did not give in to initial difficulties and did not take anything for granted. They were aware that listening to and learning from others, questioning themselves, and sharing experiences were the keys to opening new horizons. The feat of Deloy, Schnell, and Reinartz demonstrated that even with limited means, great achievements can be reached. Their success inspired thousands of radio amateurs around the world to continue experimenting and facing ever-new challenges, paving the way for significant advances in radio communication.

Leon Deloy, 8AB Fred Schnell, 1MO John Reinartz, 1XAM

Fig. the path of 6300 kilometers of signals between France and the east coast of the USA, in total darkness when the attenuation introduced by D region is minimal.

Map created using the DX Atlas software, www.dxatlas.com.

Conclusion

The ionosphere always holds surprises. After many years of study, we still have not fully understood the laws that govern it. There are numerous variables at play, and the need for conditionals is evident in many instances. My contributions are merely observations and attempts to find solutions for the often very complex phenomena that intrigue me. This aspect of our activity is undeniably fascinating. I extend an invitation to the community of radio amateurs to observe these phenomena and diligently record everything that piques our curiosity. Collaboration from everyone is essential to enhance our understanding of this enigmatic "sea" called the Ionosphere, hovering above us. I firmly believe that a multitude of experiences leads to knowledge, and a wealth of knowledge contributes to science.

THE ONLY TRUE WISDOM IS IN KNOWING YOU KNOW NOTHING.

(SOCRATE)

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Author

Flavio Egano was born in Lugo di Vicenza in 1965 and grew up between the Astico river and sports. He learned the basics of tennis from the wall of his home garage. He aspired to be a professional tennis player but soon realized it would not work out.

He found a job in a large multinational company, where he has been working until now. Despite his career, he pursued his passion for writing about tennis, sports, and Amateur Radio, hoping it would not be a disaster for literature.

Flavio graduated as an Expert in Electronics in 1984, from the State Industrial Technical Institute "G. Chilesotti" in Thiene. He also attended university courses at Chalmers University of Technology in Gothenburg, Sweden, and obtained a certificate of study in earth sciences: "Sensing Planet Earth (From Core to Outer Space and Water and Ice)."

Since 1990, he has been a radio amateur with a keen interest in studying the Ionosphere and radio propagation on amateur radio bands. In 2010, he began his first experiments in EME (Earth-Moon-Earth) on the 2 meter band. Working together with Giorgio Marchi IK1UWL, he also delved into studying EME propagation and the influence of the Ionosphere on signals passing through it.

They actively participate in various national and international conferences dedicated to the world of moon propagation (EME), where they present the results of their research.

Apart from his academic and radio pursuits, Flavio is a great sports enthusiast, particularly in tennis, which he still actively practices.

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Bibliography

SKIYMET Meteor Radar Flux by Andoya Rocket Range-Norway.
NOAA (National Atmospheric and Ocean Administration).
Articoli vari di Marino Miceli, I4SN.
School of Physics, University of New South Wales, Sydney-Australia "The Lunar tide in Sporadic E"
Mid Latitude Sporadic E - Michael Hawk.
Newton - Lo spettacolo della Scienza.
Dx Radius in Aurora and FAI radio propagation Volker Grassmann, DF5AI.
Naval Research Laboratory Washington, DC.
Earth's Ionosphere-Tor Hagfors, Kristian Schlegel - Max Planck Institute of Aeronomy, Katlenburg-Lindau, Germany.
Atmospheric Gravity waves - Prof. Michael P. Hickey, Dipartiment of Physics and Astronomy- Clemson University, South Carolina.
Department of Physics and Astronomy - University of Western Ontario - A Short Primer on Gravity waves.
EME system di F1EHN, software Moon tracking.
WSJT di Joe Taylor, K1JT.
144 MHz EME basic weak signal VHF by Tim Marek, K7XC.
Space communications (physics Princeton university).
Geophysical Institute, University of Alaska.
What are sprites? Jeremy Thomas.
Matt Heavner, Red sprites and blue jets.
Articoli vari di Marino Miceli, I4SN.
Lo strato E sporadico R.R. di M. Martinucci, IN3WWW.
UKSMG Six news Archives.
Mid Latitude Sporadic E - Michael Hawk.
Newton - Lo spettacolo della Scienza.
Dx Radius in Aurora and FAI radio propagation Volker Grassmann, DF5A.I
Naval Research Laboratory Washington, DC.
Earth's Ionosphere-Tor Hagfors, Kristian Schlegel - Max Planck Institute of Aeronomy, Katlenburg-Lindau,

Germany.
Atmospheric Gravity waves - Prof. Michael P. Hickey, Department of Physics and Astronomy- Clemson University, South Carolina.
www.vhfdx.de.
Department of Physics and Astronomy - University of Western Ontario - A Short Primer on Gravity waves.
Geophysical Institute, University of Alaska.
What are sprites? Jeremy Thomas.
Matt Heavner, Red sprites and blue jets.
IMO International Meteor Organization.
SAURA MF Radar.
NOAA - National Oceanic and Atmospheric Administration – Usa.
The shock acoustic waves generated by earthquakes - Annales geophysicae (2001) 19:395-409
ESA - Agenzia spaziale Europea.
Annales Geophysicae (2001) 19: 395 – 409.
The shock-acoustic waves generated by earthquakes.
E. L. Afraimovich, N. P. Perevalova, A. V. Plotnikov, and A. M. Uralov.
Onde radio nella banda LF e precursori sismici di R. Manno.
La previsione dei terremoti E. Barsanti.
INGV - Istituto nazionale di Geofisica e Vulcanologia Roma.
Geomagnetic Variations in the ionosphere - Department of Physics & Astronomy University of Nigeria, Nsukka, Nigeria.
50 MHz F2 Propagation Mechanisms by J. R. Kennedy K6MIO/KH6, Gemini Observatory*, Hilo, Hawaii.
IPS Radio & Space Service-Australia.
Articoli vari tratti da Radio Rivista di Marino Miceli, I4SN.
The 160-meter band: An enigma shrouded in mystery by C. Oler and Dr. T. J Cohen, N4XX.
Long path and skewed propagation in the lower shortwave frequencies by B. Tippett, W4ZV.
Luci e ombre di una propagazione di confine F.Magrone-radioascolto.org.

Long term trends in the lower ionosphere by J. Lastovicka - Institute of Atmospheric Physics, Prague-Czech Republic.
website www.avmeteo.it.
Skewed paths to Europe on the low bands by C. Luetzeschwab, K9LA.
NOAA National Oceanic and Atmospheric Administration.
NASA National Aeronauitcs and Space Administration.
Meteorologia-Atlanti scientifici Giunti.
"Electromagnetic wave propagation by conduction” by Yuri Blanarovich, VE3BMV.
NOAA (National Atmospheric and Ocean Administration).
Articoli vari di Marino Miceli, I4SN.
Mappe realizzate con il programma DX ATLAS.
UKSMG Six news Archives.
Mid Latitude Sporadic E - Michael Hawk.
Newton - Lo spettacolo della Scienza.
Atlanti scientifici Giunti, Meteorologia.
Dx Radius in Aurora and FAI radio propagation Volker Grassmann, DF5AI.
Naval Research Laboratory Washington, DC.
Earth's Ionosphere-Tor Hagfors, Kristian Schlegel - Max Planck Institute of Aeronomy, Katlenburg-Lindau, Germany.
Atmospheric Gravity waves - Prof. Michael P. Hickey, Department of Physics and Astronomy- Clemson University, South Carolina.
Department of Physics and Astronomy - University of Western Ontario - A Short Primer on Gravity waves.
Geophysical Institute, University of Alaska.
What are sprites? Jeremy Thomas.
Matt Heavner, Red sprites and blue jets.
H.A.A.R.P. High Frequency Active Auroral Research Program, Alaska-USA.
ARRL Handbook.
Max Planck Institute of Aeronomy, Germany.
Darrel Emerson- Attenuation at VHF in Propagation through the Ionosphere.
College of Engineering, The University of Iowa.

References

NOV 1997 – QST - ARRL Sporadic E. A Mystery Solved? Part 2 Author: Whitehead, Dr. David.
An explanation for the seasonal dependence of midlatitude sporadic E layers C. Haldoupis,1 D. Pancheva,2 W. Singer,3 C. Meek,4 and J. MacDougall - GFZ Helmotz centre Potsdam –Germany.
«Semidiurnal tidal signature in sporadic E occurrence rates derived from GPS radio occultation measurements at higher midlatitudes » C. Arras1, C. Jacobi2, and J. Wickert1 Helmholtz Centre Potsdam, German Research Centre for Geosciences (GFZ), Department 1: Geodesy and
University of Leipzig, Institute for Meteorology, Germany. Annales Geophysicae.
Meteogelo, Flavio Scolari.
A tutorial review on Sporadic E layers Christos Haldoupis - Physics Department, University of Crete, Heraklion, Crete, Greece.
"Global Observation and Analysis of Sporadic E layers using GPS radio occultation measurements“by C.Arras,J.Wickert,S.Heise,T.Schmidt. Helmotz Centre Potsdam.
"An explanation for the seasonal dependence of midlatitude sporadic E layers “JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, A06315, doi:10.1029/2007JA012322, 2007.
Lo strato E sporadico Origini e ipotesi di un nuovo modello esplicativo, Mimmo Martinucci, I2WWW- Radio Rivista.
University of Utrecht- Olanda.
Articoli vari di Marino Miceli, I4SN.

Decameter mid -latitude sporadic E irregularities in relation with AGW Atmospheric gravity waves.
Annales Geophysicae 15, 925-934 Anno 1997.
A. Bourdillon Laboratorie Structures Rayonnautes, LIPRES 4 CNRS 6095 Universite' de Rennes France.
E. Lefur - Laboratorie Structures Rayonnautes, LIPRES 4 CNRS 6095 Universite' de Rennes France
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J. Menard France Telecom CNLT/LAB/SAR/TSI Lannion France.
J. Delloue Laboratoire de Physique de l'Exosphère, Université' Pierre et Marie Curie, Paris-France
On the Spectrum of mid-latitude sporadic-E irregularities.
Annales Geophysicae 18, 1283-1292   Anno 2000.
Yu.V. Kyzyurov-Main Astronomical Observatory NASU, Kyiv -Ukraine.
Sporadic-E associated with the Leonid meteor shower event of November 1998 over low and equatorial latitudes.
Annales Geophysicae 19, 59-69 Anno 2001.
H. Chandra-Physical Research Laboratory, Ahmedabad-India.
S. Sharma-Physical Research Laboratory, Ahmedabad-India.
C.V. Devasia-Space Physics Laboratory, VSSC, Trivandrum-India.
K.S.V. Subbarao-Space Physics Laboratory, VSSC, Trivandrum-India.
R. Sridharan-Space Physics Laboratory, VSSC, Trivandrum-India.
J.H. Sastri-Indian Institute of Astrophysics, Bengaluru-India.
J.V.S.V. Rao-Indian Institute of Astrophysics, Bengaluru-India.
More evidence for a planetary wave link with mid latitude E region coherent backscatter and sporadic E layers.

Annales Geophysical 18, 1182-1196 Anno 2000.
Annales Geophysical - European Geophysical Society.
Modeling of Sporadic-E Structures from Wind-Driven Kelvin-Helmholtz Turbulence by Paul A. Bernhardt Plasma Physics Division Naval Research Laboratory Washington and Joseph Werne Colorado Research Associates Division Northwest Research Associates, Inc. Boulder
And Department of Physics Clemson University Clemson.
ARRL Handbook.
FADING OF HIGH FREQUENCY RADIO SIGNALS PROPAGATING IN THE IONOSPHERE - RESULTS FROM THE JINDALEE RADAR EXPERIMENT by Kin Shing Bobby Yau School of Electrical and Electronic Engineering, The University of Adelaide, South Australia 5005, Australia
Dynamical Meteorology - (IMAU, Utrecht University) del
GFZ German Research Centre for Geosciences.
Whale H.A. (1969) Duct Propagation. In: Effects of Ionospheric Scattering on Very-Long-Distance Radio Communication. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-6545-5_20.
Università di Padova- Corso di Elettronica e Telecomunicazioni G. Lullo.
INFN Istituto Nazionale di Fisica Nucleare sezione di Trieste Edoardo Milotti.
Università di Lipsia Istituto di Meteorologia.
ITU – Report ITU-R P.2011-1 Propagation at frequencies above the basic MUF.
Modellazione di strutture sporadiche-E da turbolenza Kelvin-Helmholtz guidata dal vento Di Paul A. Bernhardt Divisione di fisica del plasma Naval Research Laboratory Washington e Joseph Werne Colorado Research Associates Division NorthWest Research Associates, Inc.
E Dipartimento di Fisica Clemson University Clemson.
Engineering, The University of Adelaide, South Australia 5005, Australia.
VOACAP online http://www.voacap.com/prediction.html.
Ionospheric Radio Propagation by U.S. Department of Commerce - National Bureau of Standard.

Wikipedia.
- Aspects of Weather and Space Weather in the Earth’s Upper Atmosphere: The Role of Internal -----Atmospheric Waves by Michael C. Kelly.
- INGV istituto nazionale di Geofisica e Vulcanologia.
-Total Electron Content Studies of the Ionosphere John A. Klobuchar, Air Force Cambridge Research - Laboratories L. G. Hanscom Field, Massachusetts.
- The Potential of Broadband L-Band SAR Systems for Small Scale Ionospheric TEC Mapping (Remote Sensing Technology Institute, German Aerospace Center (DLR) Oberpfaffenhofen, D – 82234 Wessling, Germany).
- Institute of Communication and Navigation, German Aerospace Center.
- Geomagnetism Tutorial Whitham D. Reeve Observatory Anchorage, Alaska USA.
- Frederick University, 7 Y. Frederickou St., Palouriotisa, Nicosia 1036, Cyprus.
- Electron density measurements of the plasmasphere – experimental observations and modelling studies.
- Cooperative Research Centre for Satellite Systems Department of Physics, La Trobe University Bundoora, Australia.
- Propagation Factors in Space Communications (NATO).
- Seasonal variations of storm-time TEC at European middle latitudes Royal Meteorological Institute (RMI), Belgium.
- Radio Wave Propagation by Lucien Boithias, published by North Oxford Academic.
- Cleo Loi, Australian astrophysicist graduate at the University of Sydney School of Physics.
- CAASTRO, ARC Centre of Excellence for All-sky Astrophysics- Australia.
-Science Foundation for Physics - The University of Sydney.
-The Murchison widefield Array.

-Density duct formation in the wake of a travelling ionospheric disturbance: Murchison Widefield Array observations (Journal of Geophysical Research)
DF5AI Dr. Volker Grassman, www.df5ai.net.
WSJT di Joe Taylor, K1JT.
144 MHz EME basic weak signal VHF by Tim Marek, K7XC.
ARRL Handbook.
Lunar chart from**:** Lunar and Planetary Institute **-** 3600 Bay Area Blvd. **-** Houston, TX 77058
University of Virginia- USA.
Nasa - Lunar networks.
Google maps.
Prof. Manabu Kato - Science Manager of Kaguya

“A survey of ionospheric effects on space-based radar” by Zheng-Wen Xu1,2,3, JianWu2 and Zhen-Sen Wu1.

School of Science, Xidian University, Xi’an 710071, Shaanxi, People’s Republic of China. National Key Laboratory of the Electromagnetic Environment, China Research Institute of Radio wave Propagation, PO Box 6301, Beijing 102206, People’s Republic of China. Complex-signal scintillation Fremouw I, R. L. Leadabrand, R. C. Livingston, M.D. Cousins, C. L. Rino, B.C. Fair, and R. A. Long SRI International, Menlo Park, California 94025. Comparison of Ray Tracing through Ionospheric Models, Aune, Shayne C., 2d Lt, USAF. Multifrequency studies of ionospheric scintillations R. Urneki, C. H. Liu, and K. C. Yeh Department of Electrical Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801. Radio Star Scintillations from Ionospheric waves J.W. Warwick – Radio Science (Journal of Research).
Interhemispheric

transport of metallic ions within ionospheric sporadic E layers by the lower thermospheric meridional circulation.
Yu, B., Xue, X., Scott, C. J., Wu, J., Yue, X., Feng, W., Chi, Y., Marsh, D. R., Liu, H., Dou, X., and Plane, J. M. C.: Interhemispheric transport of metallic ions within ionospheric sporadic E layers by the lower thermospheric meridional circulation, Atmos. Chem. Phys., 21, 4219–4230, https://doi.org/10.5194/acp-21-4219-2021, 2021.